Aguas do Imperador – Petropolis, Rio de Janeiro State, Brazil

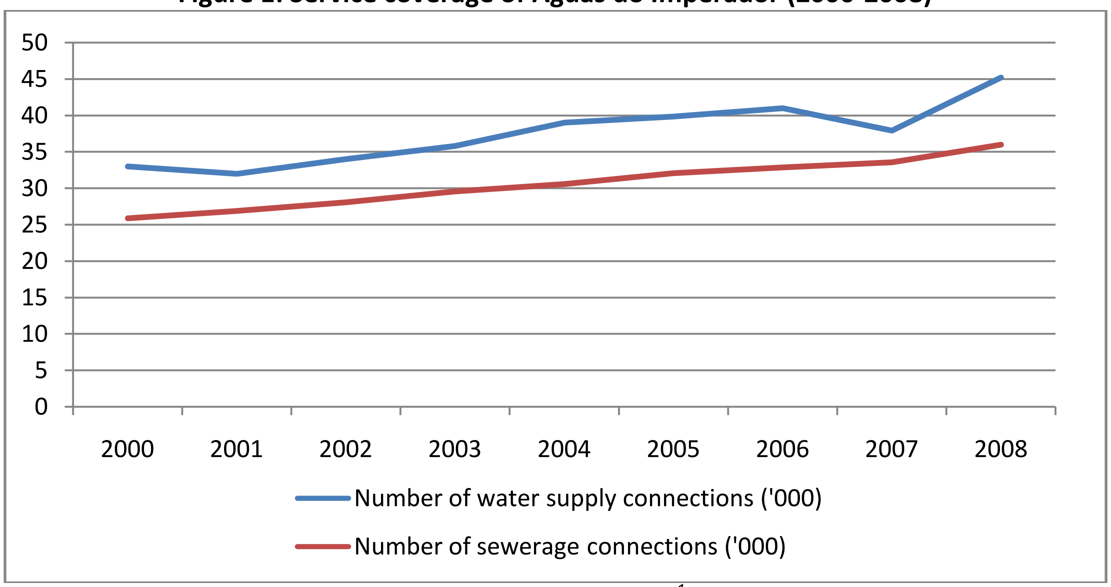
Background

Águas do Imperador (ADI) serves the municipality of Petrópolis in the mountains near the city of Rio de Janeiro. Petrópolis has a population of about 300,000 which has been growing slowly. It was the summer capital of Brazil during the time of the monarchy in the nineteenth century and is a tourist destination. The city is relatively prosperous. But much of the infrastructure is old.

ADI provides both treated water supply and sewage collection and treatment services. The concession was privatized in 1998 and extends until 2027. The holding company, Águas do Brasil, which owns ADI, also controls nine other municipal water and sanitation utilities in the States of Rio de Janeiro and São Paulo.

At the time of the privatization in 1998 there were 24,000 connections supplying less than 60 percent of the population. In the 11 years since then, there has been a substantial expansion of the infrastructure for water supply. Seven new water treatment plants and 280 km of lines have been built. In 2009 there were 47,000 connections and tap water service had reached 91 percent of households. ADI currently operates 29 wells and 22 intakes for surface water, together with 31 reservoirs. Figures 1 and 2 show the evolution of key water supply parameters between 2000 and 2008.

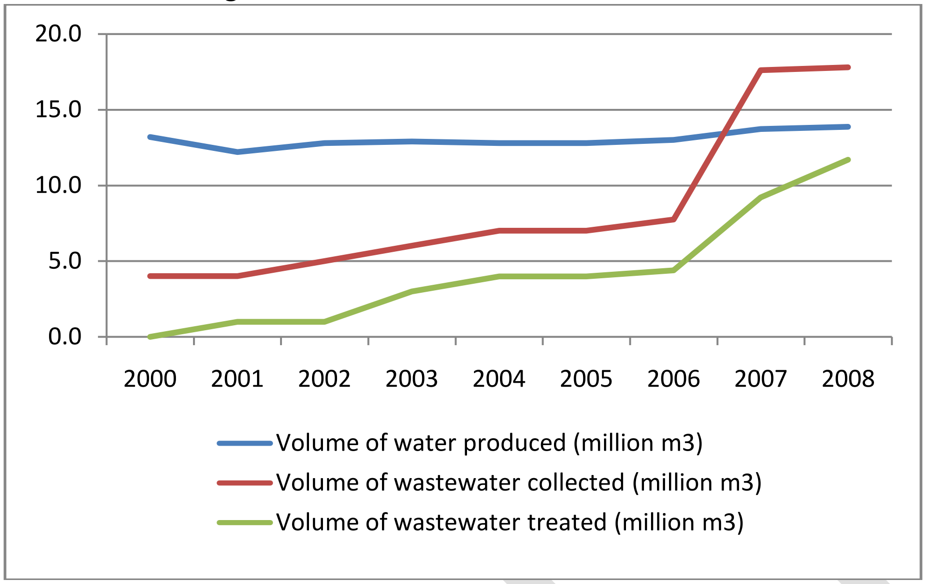
Figure 1: Service coverage of Aguas do Imperador (2000-2008)



Source: IBNET and SNIS[1]

[1] IBNET stands for International Benchmarking Network for Water and Sanitation Utilities. SNIS stands for Sistema Nacional de Informações sobre Saneamento (SNIS) – National Information System on Water, Sanitation and Solid Waste.

Figure 2: Water and Wastewater Volumes 2000-2008



Source: IBNET and SNIS

Note: ADI is also collecting and treating wastewater from surrounding areas resulting in the high numbers of wastewater collection and treatment since 2007

Water losses in 1998 were very high at almost 60 percent. Reducing them dramatically was an early priority. In 2009 nonrevenue water stood at 29 percent; by that time, 98 percent of customers had meters. Large reduction in NRW has enabled ADI to serve more people (almost doubling connections from 1998 to 2008), especially low-income households, with only moderate increase in water production.

In 2000 fifty six percent of households had sewage connections. This had increased to 66 percent in 2008 and is planned to be increased to about 80 percent in the course of 2010. Meanwhile, the share of collected wastewater which is treated increased from only 4 to 66 percent. This expansion of coverage has been accompanied by significant new infrastructure: two big sewage treatment plants and 90 km of sewage collection lines have been built since privatization. Because of the expansion on the wastewater treatment capacity ADI started to treat water from neighboring areas in 2007, resulting in wastewater expanding more rapidly than water supply (Figure 2).

The utility's revenue has been consistently above operation and maintenance costs (Figure 3), and in general should generate sufficient funds for depreciation (replacement investment). Nominal water tariffs have more than doubled, from R$1.58 in 2000 to R$3.67 in 2008.[2] In real terms, though, the price increases have been less sharp, and between 2000 and 2008 tariffs increased by about 5.1 percent annually. This steady increas in the water tariff may have also have contributed to moderate water demand growth.

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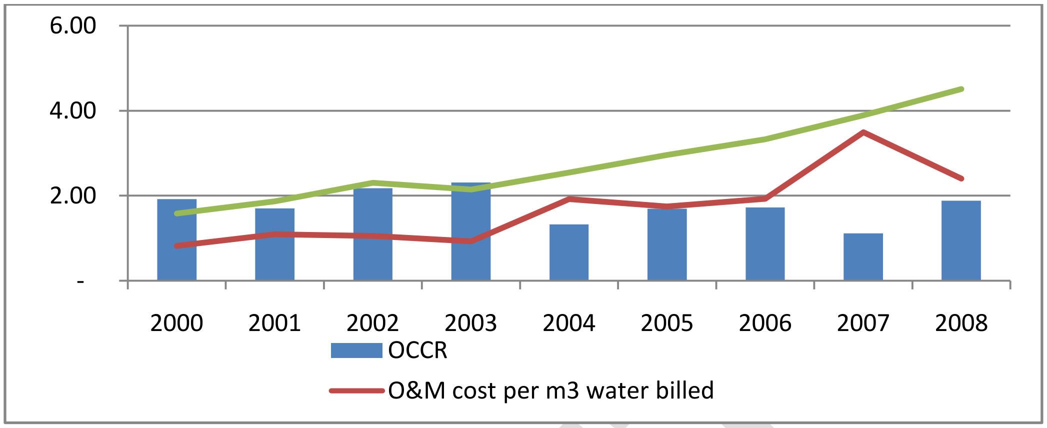
[2] Average exchange rate in December 2008 was R$1 = US$0.417.

Figure 3: Average water and wastewater tariffs, average O&M costs (in R$ per m3) and Operating Cost Coverage Ratio (OCCR)[3]



Source: IBNET and SNIS

Compared with similar-sized water and sanitation utilities in the South East Region of Brazil, ADI stood out in significantly lower NRW ratio and significantly lower energy intensity for water produced (Table 1).

Table 1: ADI benchmarked against peers, 2008.*

Year = 2008	Unit	ADI	*Others**
Households with direct water connection	%	83%	97%
Households with sewer connection	%	63%	94%
Total annual water production per capita	Liters/capita/day	146.68	329.61
Total annual water consumption per capita	Liters/capita/day	103.50	185.31
Percentage of total connections metered	%	62%	86%
Non-Revenue Water	%	29%	44%
Total annual wastewater collected	million m3/year	17.82	10.54
Wastewater receiving primary treatment	%	66%	18%
Average water tariff	R$/m3	2.64	1.47
Average wastewater tariff	R$/m3	1.03	1.30
Operating cost coverage	%	1.88	1.23
Electricity use per m3 water (production volume)	kWh/m3	0.32	0.71
Electricity use per m3 wastewater (collection volume)	kWh/m3	0.10	0.15
Share of electricity costs in total O&M costs	%	11%	15%

[3] OCCR measures how far operating revenues cover O&M costs. The rule of thumb is that if the OCCP is below 1, the utility would not be able to cover its O&M costs with its revenues. If the OCCR is between 1 and 2, the revenue would be able to cover O&M, partial to full depreciation, and even capital costs as the margin increases. In reality much depends on the actual capital costs and the types of depreciation for instance.

Source: IBNET
**Median values calculated across utilities of similar size operating in the State of Sao Paulo*

Energy Consumption

ADI is supplied with electricity by Ampla. There are about 150 connections and accounts within the 212 operational units of the utility. About 42 percent of electricity is supplied at medium voltage: 12 percent with "conventional A4" [4] and 30 percent with the time-of-day and (wet and dry) season-adjusted "Green" tariff option. The remaining 58 percent is sold at low voltage and is significantly more expensive than electricity sold at medium voltage (Table 2). Of the three utilities in these case studies, ADI has the highest average electricity price due to the preponderance of consumption at low voltage.

Table 2: Average electricity prices paid by ADI, 2009

Electricity Tariff Category	Average R$/kWh
Medium voltage (Category A4)	
Conventional	0.23
Time of day - Green - Peak	*1.88*
Time of day - Green - Off Peak	*0.19*
Low voltage (Category B)	0.44-0.51

Source: ADI

Wastewater treatment was responsible for 82 percent of the growth in overall electricity consumption since 2003 (Table 3). This reflects the large increase in sewage treatment which has occurred during this period. The average price paid for electricity has fallen since 2006. This partly reflects stability in the regulated electricity tariff level and also the increasing share of energy going to wastewater treatment – a larger share of which is supplied at medium voltage and hence is cheaper than the average for water supply.

Table 3: Energy use and costs of ADI, 2000 - 2008

Year	Share of electricity in total operational cost	Total electricity cost	Annual electricity use for water production and distribution	Annual electricity use for wastewater collection and treatment	Average electricity cost
	%	R$	MWh/year	MWh/year	R$/kWh
2000	6.0%	438,733	no data	no data	no data
2001	7.7%	631,954	no data	no data	no data
2002	11.6%	968,677	no data	no data	no data
2003	15.8%	1,483,701	4,106	0	R$ 0.361
2004	14.9%	1,717,493	4,067	389	R$ 0.385
2005	10.6%	1,853,549	4,183	458	R$ 0.399
2006	11.0%	2,108,804	4,086	617	R$ 0.448

[4] This a third medium voltage category in addition to the "Blue" and "Green" tariffs. It is a "grandfathered" tariff from pre-1984 arrangements. It does appear that ADI has any Blue tariff consumption – utility data indicates that the medium voltage consumption which is not "Conventional A4" is Green.

2007	6.2%	2,189,211	3,928	1,528	R$ 0.401
2008	11.3%	2,644,321	4,476	1,695	R$ 0.429

Source: IBNET

Table 4 shows the evolution in the electricity intensity (kWh/m^3) for both treated water supply and collected and treated wastewater. There has been a tendency for the energy intensity for wastewater to increase due to the increase in the share of treated wastewater in collected wastewater. The large jump in wastewater energy intensity in 2007 and 2008 are presumably caused by the ADI's collection and treatment of wastewater from customers served by other utilities. Energy intensity in water supply has declined steadily since 2005. Data from IBNET present a more or less flat trend for energy intensity in water supply and are slightly higher in values. Available information is insufficient to resolve this inconsistency and the study team chose to use ADI's data for energy analysis.

Table 4: Energy intensity of water supply and wastewater in kWh per cubic meter, ADI

Year	Energy intensity water produced kWh/m3	Energy intensity wastewater treated kWh/m3
2004	0.300	0.115
2005	0.308	0.115
2006	0.302	0.132
2007	0.277	0.176
2008	0.267	0.279

Source: ADI

Even though electricity tariffs increased in nominal terms (with increases taken place in 2003 and 2006), in real terms electricity rates in Petropolis have declined since 2003 giving ADI less incentive to reduce their energy intensity in water supply. ADI faces very high peak hour charges in its operating units with middle voltage accounts (Table 5). That has spurred measures to shift pumping to off-peak periods.

Table 5: Evolution of medium voltage tariff levels at AMPLA

Price paid by a hypothetical medium voltage [A4: 2.3-25 kV] consumer with the same demand contracted peak and off-peak and with a 45% capacity factor) [5]

Year	Nominal Prices R$/MWh consumed			Constant Prices 2001 R$/MWh consumed			GDP deflator
	Average Price	Peak	Off Peak	Average Price	Peak	Off Peak	
2001	136.9	785.56	76.28	136.90	785.56	76.28	1.00
2002	136.9	785.56	76.28	123.83	710.57	69.00	1.11
2003	235.38	1337.7	132.37	187.21	1,063.96	105.28	1.26
2004	235.38	1337.7	132.37	173.29	984.84	97.45	1.36
2005	235.38	1337.7	132.37	161.64	918.60	90.90	1.46
2006	289.87	1584.5	168.89	187.52	1,025.02	109.26	1.55

[5] This calculation is based on the Blue Tariff. The values are representative of trends and not any absolute value.

2007	289.87	1584.5	168.89	180.77	988.15	105.33	1.60
2008	289.87	1584.5	168.89	170.75	933.35	99.48	1.70
2009	338	1890.78	192.89				

Source: Based on Resolutions of ANEEL defined tariffs[6]

Implementation of energy efficiency and nonrevenue water initiatives

Initiatives to improve operational efficiency began in 1998/1999, soon after the utility was privatized, mainly to reduce the very high level of water losses. Later, in 2002, the scope was expanded to include energy. It was at this time that ADI began piloting Energy Monitoring and Targeting (Energy M&T), with assistance from the Energy Sector Management Assistance Program (ESMAP).

ESMAP assisted in preparing the implementation plan for the Energy M&T program. ADI carried out some planned activities and with less formality than what was suggested in the plan. No formal Energy Conservation Committee (ECC) was established within ADI. Software was purchased to support the monitoring of energy. But ADI did not renew the annual subscription after the first year, indicating that the value-added of the software was not compelling for the utility. Monitoring remained at a fairly simple level, with monthly analyses in which utility bills are compared with production data. There has been no in-house electricity metering capability to supplement data from the electric utility meters – though the electric utility's readings are frequently checked. An inventory of all electro-mechanical equipment was prepared and tachometers installed in some. A communication strategy was prepared but never completed and no results on the Energy M&T program were reported. Although there is no formal ECC, energy performance review has been a regular part of the weekly operational meetings.

A major advance in monitoring took place in April, 2009 with the inauguration of the CCO (Operational Control Center) which provides integrated support to the operational sectors. The CCO shows water flow, pressure and reservoir level, plus sewage level and status in real time. There are 15 points of monitoring and control. These are strategically located to cover about half of total water supply service coverage area. In 2010 another 30 points of measurement will be added. There is still no real time monitoring of electricity use, but ADI now has better capability to identify and monitor opportunities to save energy as well as to reduce water losses.

As with other water and sanitation utilities in Brazil, the effort to improve energy performance is seen in terms of reducing operation costs. ADI's targeting is financial in nature. They have a target to reduce energy costs per m^3 water. There is no specific energy efficiency target. Consequently many measures have been intended to reduce peak load demand, to increase the power factor to eliminate fines and to renegotiate contracts with the electric utility. Since peak hour charges are very high this optimization can be quite effective in reducing energy costs. Once the utility can achieve a low capacity factor during peak hours, it is often advantageous to shift from the Blue to the Green medium voltage tariff option. Specific measures along these lines include:

[6] ANEEL – Agência Nacional de Energia ElétricaL – is the National Electricity Regulatory Agency of Brazil

- Renegotiate electricity contracts (blue to green, low voltage to medium voltage A4);
- Build simplified substations in order to switch from low voltage to medium voltage connection with lower costs;
- Install capacitors for power factor correction;
- Install timers to control peak load: during peak hours many water pumps are shut down and the utility just operates the wastewater treatment plants; and
- Build reservoirs in order to have greater flexibility for peak load management and also for more reliable water supply.

Measures which have been taken that have some element of improving energy efficiency include (i) the replacement of pumps; and (ii) the use of variable speed drives for larger pumps (>80 hp). However, the effect of the latter is relatively limited as 85 percent of ADI's pumps have a capacity of between 2 and 20 hp.

NRW can have a significant impact on the energy consumption levels. ADI has taken a set of measures to reduce water losses, that include: (i) installation of pressure reduction valves; (ii) sectorization of the water distribution network; (iii) installation of water meters for consumers; (iv) retrofit of old distribution networks; and (v) a leak detection program using the "geophone".

Table 6 provides a ranking made by ADI managers of the effectiveness and efficiency of the measures implemented as a consequence of the on-going monitoring and targeting activities, which covers both water and energy. Effectiveness is evaluated based on the reduction of energy costs generated by each measure; efficiency is evaluated based on the energy saving generated per unit of funding invested. Items are ranked on a scale from 1 to 5 (5 most important). NA (not applicable) means the measure has not been implemented.

Table 6: Effectiveness and efficiency of measures to reduce energy costs and water losses

Optimization measure	Effectiveness	Efficiency
1. Resize and/or replacement of pumps	5	5
2. Installation of high/premium efficiency motors	NA	NA
3. Installation of Variable Speed Drives	5	5
4. Installations of timers to control operation of pumps	5	5
5. Resizing and/or replacement of water pipelines	4	5
6. Pipe rehabilitation and maintenance	3	3
7. Pump rehabilitation and maintenance	4	2
8. Well rehabilitation and maintenance	5	5
9. Construction of reservoirs	5	5
10. Power factor (PF) correction		
a. New or additional bank of capacitors	5	4
b. New or additional PF controllers	NA	NA
11. Reduction of energy peak demand		
a. Installation of new or additional maximum demand controllers	NA	NA
b. Load shedding due to best operation practices	5	5

12. Installation of water meters	5	5
13. Communication and campaigns to reduce water waste by consumers	5	5
14. Reduction of water losses		
a. Distribution network rehabilitation and maintenance	5	5
b. Control of reservoirs overflow	5	5
c. Pressure control in the distribution grid	5	3
d. Improvement of maintenance practices	5	4
15. Improvement of operation practices		
a. Upgrade of procedures	4	3
b. Upgrade of automation & controls	4	3

Source: ADI managers' evaluation

ADI's goals for 2010 include adding 30 new points of monitoring to the CCO; development of a mathematical model for the system; continuing the sectorization of the network and reducing pressure in the distribution pipelines. In terms of infrastructure, two new reservoirs are planned (1000 m^3 each); three new wastewater treatment plants (140 l/s each); twenty km of water pipelines and 8 km of sewage lines. ADI hopes to extend sewage collection to 80 percent of households by the end of 2010.

Motivations for activities to reduce energy cost and NRW

The investment priorities for ADI have been system expansion (mostly with low income communities) and increased wastewater treatment. ADI also has to deal with the consequences (high water losses) of an older infrastructure than in most cities in Brazil. According to ADI's managers involved the key motivations for undertaking the monitoring and targeting activities and associated energy optimization were to reduce operational costs, especially energy costs. The importance of reducing water losses to improve energy performance was emphasized. Projecting a favorable image of the firm to its clients, including actions relevant for environmental protection were also ranked highly. Table 7 summarizes the key drivers.

Table 7 Key drivers for implementing M&T and associated measures

Possible drivers ranked on a scale from 1 to 5 (5 most important)

Possible Driver	Importance when the M&T program started	Importance now
1. High cost of energy as a share of operational costs	5	5
2. Increasing energy costs (electricity tariff increasing faster than inflation)	5	1
3. Reducing technical water losses reduces energy use	5	5
4. Reduced operational impact allows lower water tariff and lower non-payment	1	4
5. Reduced operational costs allow increase of investment capacity to expand water & sewage systems	4	4
6. Reduced operational costs improve the utility's financial performance	4	4
7. Environmental concern, as it is projects a positive image of the utility to its clients	2	5

Electricity prices were increasing quite fast both in the nominal and inflation-corrected terms until about 2006. Since then, the nominal price level for medium voltage consumers has increased by about 17%. In terms of the general inflation index IGP-M, which was (until recently) used to correct their water tariffs, the indicator price has fallen since 2006. As energy price levels increased slower than general inflation rates, energy prices have not been a preoccupation for ADI's management in recent years. This confirms the responses given to the importance of electricity price changes for undertaking EE programs in Table 3.6.

No major disincentives for energy optimizations were raised by ADI's managers. The utility can retain the gains from reducing operational costs and re-allocate resources to expand or improve service. However, one barrier to energy optimization was mentioned. Despite being a privately owned company, ADI does not use life-cycle costing in its procurement.

Organization for energy management

There is no separate formal setup for an Energy Conservation Committee providing guidance on energy management. However, energy rationalization and water loss reduction are part of the planning routine and are on the weekly operations meeting agenda. There is no systematic M&T reporting structure. There are only sporadic reports which are focused on specific projects.

Most of the work to design and execute projects is done in-house. However, the projects to provide power factor correction and to install variable speed drives were out-sourced to an engineering company which commissioned the equipment.

Financing for energy efficiency and NRW activities

In general, ADI's investments are financed out of internal cash flow, or with loans from the BNDES. In the case of energy efficiency, all investments were financed out of cash flow. ADI did not participate in any government programs to promote energy efficiency, nor has any project been financed with the local electric utility (Ampla) to improve efficiency under the public benefit wire-charge program regulated by ANEEL (the power sector regulator). This may not come as a surprise since few electric utilities have invested in EE for WSUs. Electric utility has broad choice in which demand-side management projects it wants to implement – subject to some simple regulatory criteria.

ADI can approve the implementation of measures with a simple payback of up to eight years. There is no clear priority for investments in water delivery and sewage treatment capacity over reducing costs through programs to improve energy efficiency or to reduce water losses.

Impacts of NRW and energy management activities on energy consumption

One approach to evaluate the results of programs is to analyze their impact on the energy intensity coefficients of the utility for water supply and wastewater treatment. A first rapid analysis is to determine what happened since 2003, the first year on which energy consumption data are available, making a before and after analysis assuming that the trends of 2003 would have continued. Table 8 shows the impact of energy efficiency and NRW measures over the period 2003 to 2008 (as for earlier years no data is available about the actual energy consumption). Total nominal energy costs increased by 152 percent over this period.

Table 8: Estimation of Energy Efficiency Impacts
expressed in percentage increase between 2003 and 2008

Energy Efficiency Impacts		
Total Nominal Energy Cost Increase		**78**
Price Effect	***19***	
• Effect of Nominal Price Increases	23	
• Effect of Change in Electricity Tariff Structure	-4	
• ***Volume Effect***	***50***	
○ Gross Production volume increase	92	
○ Decline in NRW	3	
○ Energy Intensity Improvements	-24	

Price Effects. A smaller part of the increase in energy costs was the result of price effects. A nominal electricity price increase was effectuated in 2006 of 23 percent (assuming that this price increase was similar along all different electricity tariffs as we only were able to collect data on medium voltage tariffs), this means that as the overall energy prices increased by 23 percent, the remainder of the effect was caused by a change in the electricity tariff structure. As can be seen in Table 9, electricity cost increased less than the nominal rates would apply saving the utility about RS$ 8,137 per year. Most of the savings were generated after 2006, when the latest electricity price increase was implemented.

Table 9: Estimation of Energy Efficiency Impacts

Year	Actual Energy Costs	Energy Cost without changes in tariff structure	Actual Energy Cost Savings (plus = cost savings)
2003	1,483,701	1,483,701	0
2004	1,717,493	1,610,173	-107,320
2005	1,853,549	1,677,023	-176,526
2006	2,108,804	2,092,841	-15,963
2007	2,189,211	2,427,926	238,715
2008	2,644,321	2,746,102	101,781
Total Additional Costs			40,687
Annual Additional Costs			8,137

Source: IBNET and SNIS

Volume or Consumption Effect. At the same time, a volume or consumption effect can be estimated. Apart from changes in the energy prices, changes in energy consumption or volumes can be observed. These volumes are affected by two factors: (1) water production and wastewater collection and treatment, and (2) energy intensity – energy use per cubic meter of water produced and wastewater collected and treated.

Because of an increase in the non-revenue water between 2003 and 2008, more water needs to be produced. The NRW effect resulted in an increase of energy use of 3 percent. It should be noted that this is hypothetical in the sense that it represents what would have happened if the trends of 2003 had continued.

Electricity intensity of water production declined by 11 percent between 2004 and 2008.

The consumption effect can be translated into energy consumption avoided compared with the baseline condition. As can be seen in Table 10 the overall consumption savings have been large. They amount to annual savings of about 600 MWh. Assuming the current nominal energy tariffs, these savings translate to average annual savings of about R$ 260,000.

Table 10: Energy Savings in MWh and in cost savings (in R$)

Year	Energy Savings in MWh			Energy Cost Savings		
	Decline in NRW	Decline in Energy Intensity	Total	Decline in NRW	Decline in Energy Intensity	Total
2003	0	0	0	0	0	0
2004	-49	6	-43	-19,037	2,401	-16,636
2005	-9	-179	-188	-3,618	-71,399	-75,017
2006	-72	12	-59	-32,094	5,558	-26,537
2007	-230	2,143	1,913	-92,346	859,840	767,494
2008	-441	1,960	1,520	-188,888	840,038	651,150
Total Savings	-801	3,943	3,142	-335,983	1,636,437	1,300,454
Annual Savings	-160	789	628	-67,197	327,287	260,091

Source: IBNET and SNIS

Conclusions and Lessons learned

From 1998 to 2009 ADI almost doubled its treated water connections and increased its treated water service coverage from less than 60% of the population to 91%. This was accompanied by a substantial reduction of NRW, from nearly 60% in 1998 to 29% (achieved in mid 2000s). As a result water production declined from 1998 to 2001 and had increased modestly since then. Its water production in 2008 was still lower than in 1998 despite the large service expansion.

The NRW reduction activities obviously have had a significant impact on energy use for water supply. Analysis based on 2003 to 2008 data indicates that NRW reduction brought about 600 MWh of annual avoided electricity consumption, about 13 percent of the electricity used for water production and distribution in 2008.

ESMAP assisted in ADI's initial efforts to control energy costs and improve energy efficiency in 2002 and advised the water utility on implementation of an energy monitoring and targeting program. There has been heightened attention to energy management and various actions have been taken including load management measures to reduce peak charges, power factor correction to avoid penalties, as well as investments in new pumps and variable speed drives. There had been an 11 percent decline of electricity intensity of water supply from 2004 to 2008, although electricity intensity of wastewater has increased due to increased treatment.

It is noted that, despite the initial planning assisted by ESMAP, ADI took up energy management in a less formalized manner. The company management was concerned about energy cost which was about 12 percent of the total operation cost. Operation staff were assigned energy management tasks and energy was a regular discussion topic during weekly operation review meetings. But the company did not find that it was necessary to set up a formal energy conservation committee and has carried on its energy management and related renovation and upgrades as part of the overall operational management. This seems logical and should work so long as the energy management accountability is clearly defined and assigned.

The notable lessons from ADI's experience are similar to those of SANASA and SANEATINS. They reinforce some of the basic elements of effective energy management in water and sanitation utilities:

1. Active energy management is part of the operation and maintenance routines and a key responsibility of operation and maintenance managers. Such accountability has to be supported by the corporate management in terms of clarifying responsibilities in the company hierarchy and allocating funds for improvement measures.

2. Sensitivity to electricity prices is the main driver for active energy management. ADI started its energy management and energy efficiency activities when energy prices were rising rapidly and has responded to the highly differentiated peak pricing regime and voltage pricing spread more forcefully because of the significant cost implications. The private management of ADI has been keen to improve financial performance by controlling operational costs.

3. Interest in and commitment to better energy management can be reinforced through low-cost measures that achieve significant cost savings in the short term. Most actions taken so far by ADI are quick payback cost control measures such as timers for peak load control and capacitors for power factor correction.

4. Institutionalizing measures to establish baseline for pre-investment activities and to ensure that short-term savings are not eroded. This usually will take longer time to achieve. In ADI's case, the establishment of the Operational Control Center will help more closely integrate all operational management and optimize controls.

5. A systematic approach to assessing and capitalizing on the energy efficiency opportunities may require a clearly defined corporate agenda on energy management and energy efficiency improvements, although this may not appear to be an apparent need for relatively small WSUs such as ADI. ADI has been handling energy management as an implicit element of operations management, was able to finance the investments related to energy management and energy efficiency with internal cash flow, and has not had sought external financing or assistance from the existing federal energy efficiency programs.

This case study was prepared by Alan D. Pool, Caroline Van Den Berg, and Feng Liu, with contributions from Elvira Morella and Pedro Paulo da Silva Filho.