# Evaluation of Carbon Credits Saved by Water Losses Reduction in Water Networks

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**Abstract**

Nowadays, sustainable urban water management is a basic objective for the water industry. In this context, a key strategy is to rationalize water and energy demands since both resources are scarce and precious. Their costs, including the environmental ones, are in average going up while the requirements to reduce greenhouse effect gases are, with passing time, also higher. These facts fully justify the efforts to manage both resources in a more efficient way.

This paper present a methodology to calculate the energy losses linked to leaks in water distribution systems and its equivalent in carbon credits (the amount of non emitted $CO_2$ to the atmosphere obtained from saving water). To assess benefits of water losses reduction, two different scenarios (a network with and without leaks) are considered. Carbon credits calculations are performed using “Pacific Institute Water to Air Models”.

The method presented is based in the energetic audit of the network, performed from the energy equation applied to the distribution system. This energetic balance establishes that the input energy, coming from reservoirs and pumps, equals to useful energy delivered to the consumers plus losses lost in leaks and pipes friction. As a prerequisite, the energetic audit requires the water balance of the system and the mathematical model of the network. Simulations are carried out using EPAnet 2.0.

Finally, to show the influence of the energy and water sources in the final results, up to four different combinations of sources are considered. From this quantitative analysis, a sensibility analysis can be easily performed and from it, adequate strategies to manage the whole water cycle in a more sustainable way, clearly identified.

## 1 Introduction

Water and energy are closely linked. Most of large-scale energy conversion processes consume water while sustainable urban water management requires significant amounts of energy. At the same time, concerns on climatic change are growing up. In this new scenario, water and energy uses must be optimized. But, as both resources are strongly coupled, a new and integral approach is required to manage them properly. In such a fascinating research field, this new approach gives rise to new challenges and opportunities.

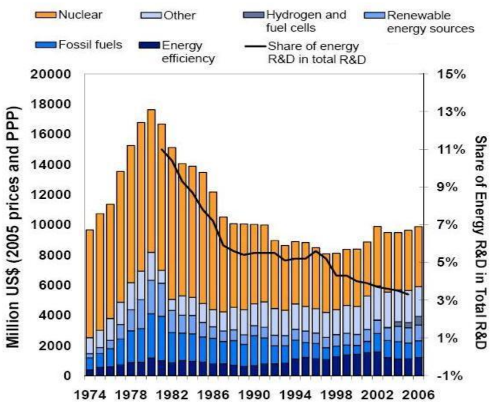


FIGURE 1. R+D INVESTMENTS IN THE IEA COUNTRIES.(IEA, 2008)

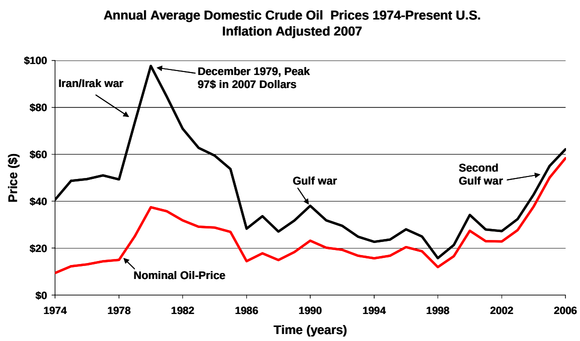


FIGURE 2. OIL PRICES IN 2007 USD$ (WWW.INFLATIONDATA.COM)

In fact, the interest in energy optimization depends on its price. This correlation is easily identified by considering the relationship between the budget devoted to R+D by member countries of the International Energy Agency (IEA, 2008) and the price of the oil barrel (Figures 1 and 2). Its comparison, although referred to dollars of different years, clearly evidences a strong correlation slightly delayed in time with the R+D expenditure. In particular, the 1973 crisis and its consequences can be easily identified. Nowadays the need to reduce the emissions of greenhouse gases is also influencing positively the R+D expenditure. Certainly this fact contributes to keep the momentum, no matter the turbulences that the oil prices are supporting.

Every step of a sustainable water cycle requires energy (kWh/$m^3$), a fact that in recent years has received a significant attention (CEC, 2005). At every step of the water cycle, water leaves its own energy footprint. Therefore, every urban or agricultural water cycle has its own energy footprint, a sensitivity analysis can be performed and so, efficient actions addressed to save energy can be easily identified. In particular, California water energy footprint range is depicted in Figure 3. In fact, it can be seen extremes values that can be found in practice at each step. According to the volumes of water mobilised in different steps of the cycle, total energy consumption of the state is 250 GWh and 19% of this consumption, 48 GWh, is consumed at facilities. Indeed, an overwhelming amount. It comes as no surprise that the US Congress shows great interest in this matter requesting to its Department of Energy a study on the issue (USDE, 2006).

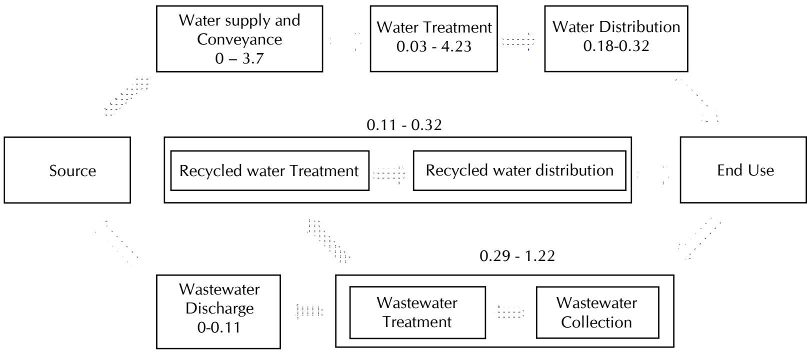


Figure 3. Water cycle ranges energy requirements (kWh/$m^3$) in California (CEC, 2005).

These facts highlights the interest of evaluating how much energy is saved by reducing the volume lost on leaks. Firstly, a methodology to perform an energy audit of water distribution networks is presented. Later on, and in order to assess energy impact, two different audits (with and without leaks) in the same network are compared. Finally, once water energy footprint of the distribution phase is known, air quality improvements can be easily assessed. The rest of the cycle has no influence in the comparison between leaky and non leaky scenario because leaked water leaves the cycle at the distribution step. Once leaked water does not consume energy although it generates a significant environmental impact.

Pacific Institute (Wolff et al, 2004) developed an excel sheet that easily relates energy with the mass of $CO_2$ emitted to atmosphere. However, there is not a straightforward relationship between the energy saved and the reduction of the mass of $CO_2$, because some other factors influence this relationship. The most important factors are energy water footprint and source of energy. To this regard, it is quite easy to understand that if water comes from a desalination plant and energy is generated by a coal fired power plant, carbon credits equivalents saved by water losses reduction are much higher than if the same leaky distribution system is supplied by groundwater and energy comes from a natural gas power plant. Table 5 and 6 at the case study presented later, highlights this fact.

Finally, further analysis may be done considering other contaminants as carbon monoxide, nitrogen oxides, sulphur oxides, etc. However, and although the procedure is the same, these other calculations are not performed here.

## 2 Revision of the structure and energy audit calculation

This section describes how to evaluate the amount of energy linked to the volume of water leaked. More details can be found in Cabrera et al (2009).

### 2.1 Input energy supplied by the reservoir (natural energy)

The external energy supplied by reservoirs or tanks is:

$$E_N(t_p) = \gamma \cdot \sum_{i=1}^{i=n_N} \left( \sum_{k=t_1}^{k=t_p} Q_{Ni}(t_k) \cdot H_{Ni}(t_k) \right) \cdot \Delta t \qquad (1)$$

Where $\gamma$ is the specific weight of water, $Q_N(t_k)$ and $H_N(t_k)$ are, respectively, the flow rate supplied from the reservoir i (being $n_N$ the number of reservoirs) and its piezometric head at time $t_k$. Since the analysis in extended time corresponds to a given period $t_p = k \cdot \Delta t$, the $k$ time intervals $\Delta t$ of the analysis must be added to totalise this period.

### 2.2 Incoming energy to the network supplied by the pumping station (shaft work)

The shaft work supplied by the pump is:

$$E_P(t_p) = \gamma \cdot \sum_{i=1}^{i=n_P} \left( \sum_{k=t_1}^{k=t_p} Q_{Pi}(t_k) \cdot H_{Pi}(t_k) \right) \cdot \Delta t \qquad (2)$$

Where $Q_{Pi}(t_k)$ and $H_P(t_k)$ are respectively the flow rate pumped by the station and the piezometric head supplied by the pump at time $t_k$. This calculation needs to be done for the $n_p$ pumping stations that supply shaft work to the system at the different time instants $k$. In this balance, and because pumps do not belong to the system, their efficiencies (an essential parameter for the energy optimization) are not included. In any case they can be easily included dividing, for each time interval, this shaft energy term by the corresponding pump's efficiency. In this paper, and since the focus is on new concepts, these energy losses are not considered.

### 2.3 Energy delivered to users at consumption nodes

The useful energy delivered is:

$$E_U(t_p) = \gamma \cdot \sum_{i=1}^{i=n} \left( \sum_{k=t_1}^{k=t_p} q_{ui}(t_k) \cdot H_i(t_k) \right) \cdot \Delta t \qquad (3)$$

Where n is the number of demand nodes of the network, $q_{ui}(t_k)$ and $H_i(t_k)$ are respectively the flow rate delivered to users and the piezometric head at node i and time $t_k$.

### 2.4 Outgoing energy through leaks

Leaks represent energy leaving the system, formally analogous to the energy delivered to users, although from the point of view of the audit is lost energy. This value is:

$$E_L(t_p) = \gamma \cdot \sum_{i=1}^{i=n} \left( \sum_{k=t_1}^{k=t_p} q_{li}(t_k) \cdot H_i(t_k) \right) \cdot \Delta t \qquad (4)$$

With n the number of leaking nodes in the network, $q_{li}(t_k)$ the leaked flow rate in the pipes adjacent to node i (and therefore associated to this node) at time $t_k$, while $H_i(t_k)$ is the piezometric head at time $t_k$ in the node where the leak $q_{li}(t_k)$ has been concentrated.

### 2.5 Friction dissipated energy in pipes

The energy dissipated due to friction is:

$$E_F(t_p) = \gamma \cdot \sum_{j=1}^{j=n_l} \left( \sum_{k=t_1}^{k=t_p} q_j(t_k) \cdot \Delta h_j(t_k) \right) \cdot \Delta t \qquad (5)$$

Where $n_l$ is the number of lines of the network, $\Delta h_j(t_k)$ are friction losses in line j at time $t_k$ (this term is in pipe j the difference in piezometric heads between the initial and final nodes, a value known from the mathematical model of the system), $q_{uj}(t_k)$ and $q_{lj}(t_k)$ are in line j respectively the flow rate necessary to satisfy the users demand and the flow rate that finally is lost through breaks. Therefore, the total flow rate in line j $q_j(t_k)$ is the sum of the two previous values. Local losses due to valves, fittings, elbows, etc. may be added to this term by calculating equivalent piping length.

## 2.6 Final balance

From the preceding terms, being $t_p$ the period of calculation of the previous expressions (commonly one year), the following final balance results:

$$E_{input}(t_p) = E_N(t_p) + E_P(t_p) = E_U(t_p) + E_L(t_p) + E_F(t_p) = E_{Output}(t_p) + E_{Dissipated}(t_p) \tag{6}$$

Equation (6) states that the energy (natural and shaft) supplied to the water coming into the network is equal to the energy delivered to the users (throughout the water supplied) plus the losses (leakage and mechanical friction). From this balance, energy losses can be evaluated and its knowledge allows outlining efficient actions aimed to improve system's efficiency.

# 3 Network example

Water distribution system is illustrated in Figure 4 (complementary data are listed in Table 1). From the audit, water energy footprint corresponding to this step will be evaluated. Although in practical cases can be easily included, efficiency of the pump is not considered. Simulations are performed using the EPANET2 (Rossman, 2000).

Basic network data:

- Total pipe length: 40 Km
- Water delivered to costumers registered by meters: 1.25 $Hm^3$/year
- Water supplied:
  - 1.25 $Hm^3$/year (non-leaky scenario)
  - 1.89 $Hm^3$/year (leaky scenario)
- Leaked water:
  - 0.64 $Hm^3$/year, equivalent to 1.82 $m^3$/km/h
- The minimum service pressure: 25 m.

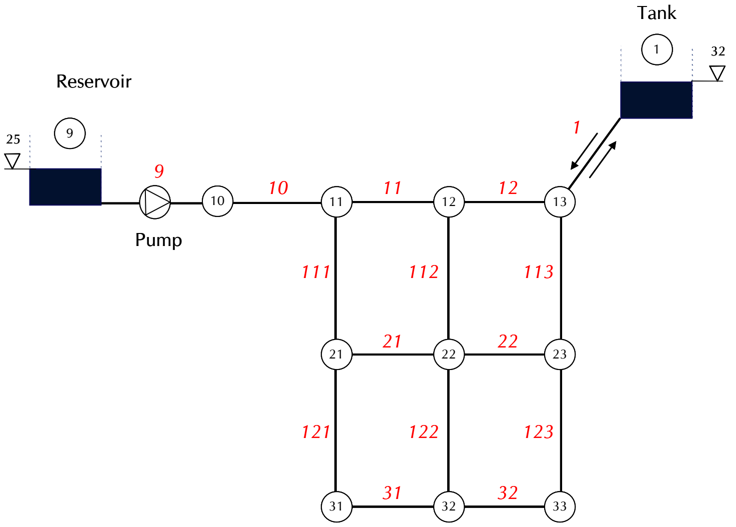


Figure 4. Layout of the network

The diameter of the compensation tank is 20 m and its minimum level 2 m (the initial value for the simulation) while the maximum level is 7 m. To avoid overspill, a control law has been added (pump starts when the level is 2 m and stops at 7 m). Hourly demand pattern (Table 2) is the same for all nodes and consumers.

Table 1. Lines and nodes characteristics

| Pipe | Length (km) | Diameter (mm) | Junction | Base demand (l/s) | Elevation (m) | Emitter's coefficients ($m^{3-\alpha}/s$) |
|---|---|---|---|---|---|---|
| 10 | 2 | 400 | 10 | 0 | 5.8 | 0.0074 |
| 11 | 2 | 300 | 11 | 5 | 5.8 | 0.0294 |
| 12 | 2 | 350 | 12 | 5 | 4 | 0.0294 |
| 21 | 2 | 200 | 13 | 3 | 2 | 0.0294 |
| 22 | 2 | 200 | 21 | 5 | 4 | 0.0368 |
| 31 | 2 | 200 | 22 | 6.5 | 2 | 0.0441 |
| 111 | 4 | 200 | 23 | 5 | 0 | 0.0368 |
| 112 | 4 | 250 | 31 | 3 | 4 | 0.0221 |
| 113 | 4 | 300 | 32 | 3 | 5 | 0.0294 |
| 121 | 4 | 200 | 33 | 3 | 0 | 0.0221 |
| 122 | 4 | 200 | Reservoir | - | 25 | - |
| 123 | 4 | 200 | Tank | - | 32 | - |
| 32 | 2 | 200 | | | | |
| 1 | 2 | 400 | | | | |

Table 2. Hourly demand pattern

| **Time** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Coefficient | 0.6 | 0.5 | 0.45 | 0.45 | 0.5 | 0.5 | 0.9 | 1.3 | 1.4 | 1.1 | 1.5 | 1.4 |
| **Time** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** | **22** | **23** | **24** |
| Coefficient | 1.4 | 1.45 | 1.45 | 1.3 | 1.2 | 1.2 | 1.1 | 1.1 | 1.2 | 1.1 | 0.9 | 0.7 |

It is assumed that leaks are uniformly distributed loaded at demand nodes as explained in Almandoz et al. (2005). Leaks are modelled as discharge valves and their emitter's coefficients are those of Table 1. The characteristics of the emitters follow equation: $q_{li}(t_k) = C_E \cdot \Delta H^{\alpha}$ , according the EPANET model. Being $C_E$ ($m^{3-\alpha}$ /s) the emitter's coefficient corresponding to each node, $\Delta H$ (m.c.w.) the difference of pressure throughout the failure while $\alpha$ =1.2 is the emitter exponent. This exponent is higher than 0.5 because it takes into account pipe material, elasticity, etc.

To provide the necessary energy to maintain at any time the pressure level above the standards, a pump is installed downstream the reservoir. The head-flow curve of the pump is defined by: $H = 93.33 - 0.003646 \cdot Q^2$ .

## 3.1 Energy required at distribution step

To evaluate one year energy's requirements, the procedure outlined in section 2 has been applied to the network showed in Figure 4. Results, for both leaky and non leaky network, are summarised in Table 3.

These are the comments obtained from Table 3 results:

- The total energy required to satisfy the demand for the leaky network case is 50% higher than for the non leaky network (326,55 and 219.64 MWh respectively).
- The shaft energy supplied to water coming into the network is higher (around 60%) than the natural gravitational energy (about 40%). Both cases require a similar percentage.
- As expected, dissipated energy term in the leaky network is considerably higher than in the non leaky one, although in relative terms is smaller because the influence of the leaky energy.
- The energy lost due to the leaks is the increment of friction energy between cases (132.27 – 91.93 MWh) plus the energy lost through leaks (67.53 MWh).

It should be recalled that the yearly water delivered to the consumers is 1.25 $Hm^3$ while leaked water in the same period of time in leaky network is 0.64 $Hm^3$. From the absolute values shown in Table 3, water energy footprint of the distribution step ($kWh/m^3$) can be easily determined. Table 4 shows these results that are of the same order of magnitude (see Figure 3) than those corresponding to the state of California (0.18 - 0.32 $kWh/m^3$). At Table 4, the first column represents the total energy required per cubic meter, while the following ones show the origin of this energy (natural or shaft). Obviously, at non leaky network, delivered water to consumers is equal to water supplied.

Table 3. Energy Audit (MWh/year).

<table>
<tr><td rowspan="3">Non Leaky network</td><td rowspan="2">$E_N(t_p)$=84.84 (38.6%)</td><td rowspan="5">$E_{Input}(t_p)$=219.64</td><td>$E_U(t_p)$=127.71 (58.15%)</td><td rowspan="2">$E_{Output}(t_p)$=127.71 (58.15%)</td></tr>
<tr><td>$E_L(t_p)$=0</td></tr>
<tr><td>$E_P(t_p)$=134.8 (61.4%)</td><td>$E_F(t_p)$=91.93 (41.85%)</td><td>$E_{Dissipated}(t_p)$=91.93 (41.85%)</td></tr>
<tr><td rowspan="3">Leaky network</td><td rowspan="2">$E_N(t_p)$=129.08 (39.53%)</td><td rowspan="3">$E_{Input}(t_p)$=326.55</td><td>$E_U(t_p)$=126.48 (38.76%)</td><td rowspan="2">$E_{Output}(t_p)$=194.01 (59.46%)</td></tr>
<tr><td>$E_L(t_p)$=67.53 (20.70%)</td></tr>
<tr><td>$E_P(t_p)$=197.47 (60.47%)</td><td>$E_F(t_p)$=132.27 (40.54%)</td><td>$E_{Dissipated}(t_p)$=132.27 (40.54%)</td></tr>
</table>

Table 4. Water footprint energy of the distribution step (kWh/m$^3$)

| **Leaky Network** | | | | **Non Leaky Network** | | | |
|---|---|---|---|---|---|---|---|
| | $E_{Input}(t_p)$ | $E_N(t_p)$ | $E_P(t_p)$ | | $E_{Input}(t_p)$ | $E_N(t_p)$ | $E_P(t_p)$ |
| (m$^3$) supplied | 0.172 | 0.068 | 0.104 | (m$^3$) supplied and delivered | 0.176 | 0.068 | 0.108 |
| (m$^3$) delivered | 0.261 | 0.103 | 0.158 | | | | |
| (m$^3$) leaked | 0.168 | 0.069 | 0.098 | (m$^3$) leaked | - | - | - |

Last, it is important to underline that the energy supplied by the reservoir (natural energy) cannot be included in the water to air model. In this phase, just the shaft energy associated to leaks (0.098 kWh/m$^3$) must be taken into account. And for sure, the energy delivered to leaked water in previous steps (as transport or treatment) must be included as well.

# 4 Equivalent credits of carbon

As mentioned earlier, Pacific Institute developed a model to calculate air quality implications derived of the energy requirements of urban and agricultural water cycles (Wolff et al., 2004). First, the model requires water energy footprint which depends on the water origin (surface water, groundwater, desalination, etc.). As mentioned before, last step to be considered in this footprint is the distribution one (water leaked is not drained or treated). The source of the energy is required too (Natural Gas Power Plant, Oil Fired Power Plant, Coal Fired, Nuclear, etc…). To illustrate the method, typical values used for both water energy footprint and the energy are specified.

## 4.1 Influence of the power plant generation

Every energy source emits different amounts of $CO_2$ per kWh produced. Table 5 show standard values.

Table 5. Amount of $CO_2$ emitted to atmosphere per every source of energy.

| **Emission g/kWh** | **Natural Gas** | **Oil Fired** | **Coal Fired** | **Hydro/ Solar /Wind** | **Nuclear** |
|---|---|---|---|---|---|
| Carbon dioxide | 554 | 865 | 1432 | 0.0 | 0.0 |

## 4.2 Water energy footprint of the water cycle

Water, prior to be distributed, has its own energy water footprint (in kWh/$m^3$). As a matter of fact, in this paper values showed in Table 6 are used to evaluate the energy requirements of the considered water sources. Final drainage collection and waste treatment are not listed because, as said before, these steps are not walked by leaked water. In any case when water goes around the whole cycle, the corresponding values should be, indeed, included.

Table 6. Current values of the energy water footprint (from the beginning of the cycle up to the distribution phase)

| Step | Type | Order of magnitude |
|---|---|---|
| Water supply and conveyance | Groundwater | 0.35 kWh/$m^3$ per 100 m of elevation |
| | Surface Water | (0-3) kWh/$m^3$ |
| Water Treatment | Desalination | Approx. 3.65 kWh/$m^3$ |
| | Treatment | Approx. 0.04 kWh/$m^3$ |
| Water Distribution | Shaft energy | Calculated from the energy audit (0.098 kWh/$m^3$, See Table 4) |

## 4.3 Credit carbon savings

Credits of carbons saved depend very much on the sources of water and energy. To highlight it, two different water energy footprints, A and B, are considered. Case A corresponds to a utility fed 50% by local surface and 50% by groundwater (WOA). In case B water comes from a desalination plant (WOB). The water energy footprints are 0.296 kwh/$m^3$ and 3.65 kwh/$m^3$ respectively up to the distribution step and at the distribution step is 0.098 kwh/$m^3$ for both cases.

As far as source of energy concerns, again two different scenarios are considered. The first one (ES1) reproduces how the total energy is produced in Spain (MITYC, 2007). Case 2 (ES2) corresponds to a combination of the power plants which emits more tons of $CO_2$.

Table 7. Energy source

| | Natural Gas | Oil Fired | Coal Fired | Nuclear | Hydraulic | Other |
|---|---|---|---|---|---|---|
| Energy source case 1 (ES1) | 29.8% | 7.9% | 22.4% | 19.8% | 9.7% | 10.4% |
| Energy source case 2 (ES2) | 33.3% | 33.3% | 33.4% | 0% | 0% | 0% |

The carbon credits saved by a non leaky network (with regard to the leaky one) depend not only on the energy saved at the distribution step, but on the origin of water and energy as well. From the combination of the preceding sources, four different cases (WOA + ES1, WOB + ES1, WOA + ES2 and WOB + ES2) can be considered. Table 8 show the corresponding results

Table 8. Credit carbons saved.

| | ES1 | ES2 |
|---|---|---|
| **WOA** | 144 | 248 |
| **WOB** | 1351 | 2321 |

As expected, depending on the source of water and energy the final result can be significantly different. The worst situation is found when water proceeds from a very energy consuming source (as a desalination plant) supplied by energy generated by a very contaminant power plant.

Finally, taking into account that considered network is supplying water to a population of around 25000 people; credit carbons that can be saved avoiding leaks can very much contribute to avoid climate change. We cannot forget that a credit of carbon represent one $CO_2$ ton.

## 5 Conclusions

Sustainable urban water management is deeply conditioned by the circumstances of the corresponding water cycle. In order to assess each particular case, accurate water and energy audits along the water cycle must be performed. Because the complexity of the water network (hundreds of kilometres of underground pipes with thousands of domestic connections) the distribution step is the most complex phase to audit, no matter the resource (energy or water) origin.

In any case, water audits of distribution networks have received a lot of attention in the last years, particularly during the last decade although, up to now, energy audits have not deserved a similar level of attention. Water and energy are valuable resources strongly linked, as often is underlined with the sentence *saving water saves energy.* However, this qualitative sentence should be modified by *saving water saves energy and emissions as well*. But this fact has to be backed up by facts and not just by words. And facts demand quantitative analysis not just qualitative words. Since from quantitative evaluations, rational sensitivity analysis can be performed to identify the best cost benefit measure to manage water in the most sustainable way.

## 6 Acknowledgements

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## 7 References

Almandoz, J.; Cabrera E., Arregui, F., Cabrera Jr. E. and Cobacho R. (2005). "Leakage Assessment through Water Distribution Network Simulation". Journal of Water resources Planning and Management, 131(6), 458-466.

Cabrera E., Pardo M.A., Cobacho R. and Cabrera E. Jr., (2009). "Energy Audit of a water Distribution network". Journal of Water Resources Planning and Management American Society of Civil Engineering. (Under revision).

"California's Water-Energy Relationship report" California Energy Commission. November 2005 CEC-700-2005-011-SF

IEA (International Energy Agency), (2008). "Energy Technology Perspectives. Scenarios & Strategies to 2050".

MITYC, Ministerio de Industria , Turismo y Comercio (2007). "La energía en España". I.S.B.N.-13: 978-84-96275-52-2. (In Spanish).

Rossman, L. A. (2000). EPANET 2: User´s manual, U.S. Environmental Protection Agency, Cincinnati.

USDE (United States Department of Energy), (2006). "Energy Demands on Water Resources. Report to congress on the interpendency of energy and Water".

Wolff, G. Sanjay, G. and Winslow, M. "User Manual for the Pacific Institute Water to Air Models". October 2004. www.pacinst.org