Introduction

The interaction between energy and water in water reuse is bidirectional. Energy is used to make water available and usable; and water is required in most energy-generating technologies, regardless of whether they are water-based. Therefore, a double challenge is to be met: on one hand, energy use in water systems should be minimized; on the other hand, energy recovery from wastewater discharges should be maximized [26]. Either goal is dependent on the other—choices made on one end of the chain may have impacts on what happens on the other end. Therefore, the problem to be solved is not one of mere maximization, but one of optimization in technological, behavioral, and regulatory decisions. Moreover, social and environmental impacts should also be considered. Both energy use in water recycling and the technologies that are employed (if any) for energy recovery from wastewater may have adverse environmental impacts on several dimensions, such as the production of pollutants, the emission of CO₂, as well as other greenhouse gases (GHGs), etc. It may—and does—happen that a setting that minimizes a given environmental impact also results in an increase in some other environmental impacts. For example—as it will be shown—it happens that, under specific circumstances, the reduction of CO₂ increases the release in the atmosphere of other GHGs. Even from this point of view, decision makers face important trade-offs, under significant information asymmetries, lack of information, and limited ability to forecast future trends.

To make things even more complex, there is no way of assessing what is the most convenient organizational solution for a water system in principle. The choice of technologies, organizational...
settings, financial arrangements, and supply- and demand-side measures strongly depends on site-specific circumstances. To make only a few examples, it does matter a lot whether freshwater is readily available; whether supply and demand are subject to huge fluctuations (e.g., due to seasonal trends); whether water demand is driven by uses that require high- or low-quality standards; how energy is provided; whether an urban area is densely populated or sprawled out; whether wastewater treatment plants are already available and, more generally, how the existing systems—both with regard to water conveyance to its final consumption places and to wastewater collection and treatment—are organized; whether energy is easily and cost-effectively available; whether the general quality of institutions is such that investments with a long recovery time are easily made; etc. In other words, there is no “one size fits all” kind of solution—several alternatives are available, including the null hypothesis of not reusing water if abundant freshwater is available or if other alternative sources of water are more competitive (e.g., water desalination). Extreme options are hardly convenient, though. In most cases, the decision maker will have to find the right balance between technologies, approaches, and use regulations that lead to the best outcome. In this respect, it can be said that, while a “theory” of energy–water interactions in water reuse is impossible to develop, a number of case studies may provide the decision maker with the most valuable information [1].

This chapter is organized as follows. Section 3.2 deals with energy use in water reuse. Both the provision of water and the processes needed to reclaim and treat it to make it usable again are energy intensive. The choice of the best technologies for wastewater treatment, as well as the correct scale for treatment plants, is crucial in order to ensure that energy is not wasted (and hence the environment is not pointlessly harmed) either from an operational perspective or from the point of view of life-cycle assessment. Depending on site-specific features—including, but not limited to, freshwater availability, the possibility of reclaiming greywater, blackwater, and perhaps yellow water independently from each other, the origins of discharges, the existence of incentive schemes for renewable energies, etc.—it may be possible both to reduce energy demand and to increase the share of carbon-free and pollution-free energy.

Section 3.3 looks at the opposite end of the problem: energy recovery from wastewater. Energy is stored in wastewater in a variety of forms, from the potential energy of it to its heat content and the chemical energy embodied in the discharge flow. Recovering energy is therefore technically possible, although not always cost-effective. Environmental impacts of energy recovery should also be considered: often pollution is not abated, it is merely shifted from one form to another or from a recipient body to another. Sometimes this may be—on balance—environmentally benign, sometimes not. Much depends on the available technologies. In principle, the more energy recovered from wastewater, the more energy demand from wastewater treatment and water provision is reduced, and the more energy-related environmental impacts are reduced (but not necessarily all environmental impacts).

Section 3.4 is concerned precisely with environmental impacts and the much-challenging trade-offs that the decision maker has to solve. Such trade-offs involve both the opportunity cost of the choices being made, and the choice between different pollutants that may be caused by the transformation of each other (e.g., non-CO₂ GHGs might be emitted as CO₂ is abated). Such decisions have both an economical dimension and an environmental one.

Section 3.5 puts all the above against the feasibility test: all the solutions that have been presented make energy and environmental sense, but are they financially sustainable, too? Occasionally, it may be the case that local conditions make an investment worthwhile because savings of future operational expenses are evident that anyone who is in charge would go for it. However, often reshaping water provisions and reclamation and treatment systems requires major upfront investments. Their bankability depends on the degree of certainty of the regulatory environment. Therefore, a discussion of the political, legal, and regulatory conditions behind water systems is unavoidable.

Summary and conclusions are provided in Section 3.6.

### 3.2 Energy Use in Water Reuse

The amount of energy used in water provision and reuse varies significantly depending on a number of variables, of which the most important ones are site-specific and include (but are not limited to) the availability of freshwater, the availability of indigenous, carbon-free sources of energy, and the general setting of the place (urban vs. rural or industrial). With regard to this latter point, this chapter mostly deals with urban contexts. It also makes a major difference whether a water system is being designed within a developing context or it is being adjusted within an existing context. Especially historical settings may pose significant challenges in finding the right balance between the optimization of the water system and the preservation of the existing architectures, buildings, and urban structures.

The use of energy in traditional water systems used to be relatively limited: energy was needed for moving water through pipes, treating water before use, and treating wastewater in order to release it in the environment without spreading pollution [23]. Figure 3.1 shows the breakdown of energy consumption of a typical water utility.

The energy footprint of water use, however, significantly increases as alternative water sources are employed. For example, water reuse—hence the need to treat wastewater up to drinking water standards—and desalination are typically energy-intensive activities. Subsequently, the environmental footprint of alternative water sources may also be nonnegligible. However, relying on alternative water sources may become ever more important as the world population grows, as does the average income, driving up water demand, and setting up existing or potential problems of water scarcity. In fact, as the population grows larger and wealthier, a process that is typically associated with urbanization, water demand follows. As Figure 3.2 shows, the relationship between average income levels and water consumption per capita is both straightforward and clear.
It can be inferred that both population growth—which is higher in the developing world than in the developed world [24]—and economic growth will drive per capita water demand in today’s low-demand countries up toward the levels that are observed in higher-income countries. Water reuse becomes a crucial element to meet the growing demand while preventing water conflicts. Smart regulation—as it will be shown in Section 3.5—will also play a key role, as it crucially depends on the quality of institutions whether the needed investments will be performed.

In order to minimize the energy footprint of alternative water sources, three questions should be properly answered: (1) What alternative water source is best suited to meet the demand, both from an operational and from a life-cycle point of view? (2) What technological choices should be made, under (1)? (3) Given (1) and (2), how should the water system be designed and what kind of modifications are needed to the existing infrastructures?

Providing a correct answer to question (1) is particularly important in dry areas, where water scarcity poses major constraints to

![Figure 3.1](image1.png)  
**FIGURE 3.1** Breakdown of energy consumption of a water utility: (a) life-cycle phase, (b) water supply phase, (c) life-cycle activity, and (d) material production category. (Adapted from Stokes, J.R. and Horvath, A. 2009. *Environmental Science and Technology*, 43(8), 2680–2687.)

![Figure 3.2](image2.png)  
the ability of the population—particularly low-income groups—to have access to reliable and affordable water distribution and wastewater collection systems. Providing a well-functioning water cycle system is not just about enforcing the most basic human of all rights, but also about setting in place conditions for a number of epidemic diseases to be eradicated [9,12].

When the decision of relying on alternative water sources is made (or when there is no alternative to it), the decision maker is left with three options: (1) desalination (if seawater is at a reasonable distance), (2) water import (where possible), and (3) water reuse. Even though the balance may vary significantly depending on site-specific conditions, water reuse is often the least energy-intensive solution [17,22,28].

In the past, water reuse—especially for drinking purposes—had to overcome two major challenges: cost and public acceptance. Significant technological progresses in membrane filtration (with regard to both microfiltration and ultrafiltration) as well as in reverse osmosis (RO) technologies helped to tackle the former problem. Public acceptance is gradually being achieved, in part because populations around the world are becoming more aware of the size of the water challenge and the importance of not wasting water resources, especially in water-poor areas. Energy is an important input for water and wastewater treatment. Given the wide spectrum of available technologies—as well as the large differences in the quality, quantity, and regularity of the feedstock—the drivers of energy consumption may vary significantly. Figure 3.3 shows the breakdown of energy consumption for the typical treatment plant.

From Figure 3.3, it is evident that the most energy-intensive features of a conventional wastewater treatment plant are aeration of the activated sludge, which accounts for 45% of total energy consumption, and then—much less relevant—odor treatment, auxiliary equipment, and pumping, which account for 12%, 10%, and 8%, respectively. Three quarters of total energy demand is connected with the above-mentioned components. It follows that energy-saving efforts in wastewater treatment should be focused on these parts of the plant. Beyond the specific available technologies [2,3,9], attention should be paid to the general design of the system, of which the wastewater treatment plant is but the last step. In fact, the efficiency of the aeration system (and more broadly of the whole plant) may be increased if the wastewater inflow is more foreseeable and regular; on the other hand, energy consumption may be lower if the outflow of water may be directed toward nondrinking uses, whereby lower quality standards are acceptable. Clearly, under this latter hypothesis, fewer treatments are necessary and energy requirements are accordingly lower.

In other words, energy consumption in wastewater treatment may be reduced both by employing more efficient technology, and by improving the quality of the input (as well as reducing the required quality of the output). In either case, a different design is required from that which has historically characterized water distribution and wastewater collection systems [5]. The key concept is that multiple sets of pipes should be put in place, in order to better discriminate between alternative uses of water. This would also help to solve the social acceptance dilemma. If households could rely on freshwater for drinking, kitchen, and bathing purposes, and on recycled water for other uses (most notably toilet flushing and perhaps washing machines), they might have less to object because they would feel less unsafe (although there is no reason to believe recycled water is less safe than freshwater).

By the same token, what in most cities of today is one single flow of wastewater might be divided into two or even three separate flows: greywater (i.e., water used for bathing, laundry, etc.), blackwater (which includes feces and water from the kitchen and the like), and perhaps yellowwater (urine). Greywater is the largest contribution to wastewater, and also the least contaminated one; blackwater has the highest content of biodegradable organic matter that needs to be depurated, but also has the highest potential for energy recovery; and yellowwater contains the vast majority of such nutrients as nitrogen, phosphorus, and potassium. Separate collection of yellowwater may be very costly or even impossible in historical settings, but it may be a useful improvement in new development areas.

Dual distribution systems and separate collection might be necessary to achieve two distinct, but interrelated, results: on one hand, minimizing energy consumption in water reuse, and on the other hand, maximizing energy recovery from wastewater. This is the subject of the next section.

3.3 Energy Recovery from Wastewater

Energy is used at every step of the water system. Energy is needed for water abstraction, purification, and distribution;
Energy is consumed to reclaim, treat, and release wastewater into the environment; and energy is needed to make water reuse possible when and if it seems convenient based on general or site-specific conditions, as well as on policies oriented at saving water and, when applicable, energy (in fact, it is not obvious that water reuse implies energy savings, and vice versa, while it is generally true that a well-designed water system allows for both water and energy savings).

Energy is not just spent on the water cycle: it is also transported by water and wastewater themselves, and on some occasions it is even injected into water (e.g., when cold water is heated—for kitchen or bathing uses—and then flushed, or when organic matter—such as feces—is added to water and then sent down to the sewage).

In particular, as Figure 3.4 shows, energy is present in—and can theoretically be reclaimed from—water and wastewater in four forms [13]:

- Kinetic energy
- Potential energy
- Thermal energy
- Chemically bound energy

The amount of energy attributable to each of these forms varies significantly; it depends on local conditions and it cannot always be recovered in a cost-effective way, leaving aside the technical aspects of energy recovery from wastewater.

Kinetic energy depends on the speed of water and wastewater flows. As these are generally very slow, the amount of recoverable energy is accordingly low, and generally it is not worth the cost. However, at particular points within the system, the speed of water flows may be higher, in which case—based upon site-specific features—energy recovery may be economically as well as energetically convenient.

Potential energy depends on the height. Even this potential source of energy does not appear very promising. A simple calculation will explain why. Potential energy follows the following well-known formula:

\[ U = mgh \]

where \( U \) is the potential energy; \( m \) is the mass of water or wastewater; \( g \) is standard gravity, that is, an acceleration of approximately 9.8 m/s² due to the Earth’s gravitational attraction; and \( h \) is the height.

It follows that, under the assumption of a standard wastewater flow rate of 0.15 m³ per person per day, heights of as much as 10, 30, or 50 m imply a potential energy content (ignoring losses) of as much (or as little) as 14.7, 44.1, or 73.5 J per person per day, respectively, or 4.1, 12.2, 20.4 Wh per person per day, respectively.

Thermal energy depends on the heat that is embodied in wastewater flows. The heat, in turn, depends on wastewater’s temperature, which derives from the amount of hot water that is mixed with cold water from, largely, kitchen and bathing uses. While thermal energy is the most important form of energy that is bound into wastewater, it may be difficult to recover nevertheless. In order to maximize the possibility of reclaiming thermal energy, one or more of the following conditions must be met: (1) as thermal energy is easily lost to the surrounding environment, it should be reclaimed as close as possible to the source; (2) in order to reduce losses, pipes should be insulated; and (3) in order to maximize wastewater’s heat content greywater should be collected separately from other sources.

Finally, chemically bound energy—while less important than thermal energy for its size relative to the total energy content of wastewater—is the form that is most easily recovered and turned into usable energy. On one hand, wastewater can be moved wherever treatment plants are without compromising the amount of recoverable energy. On the other hand, several technologies are available to maximize energy recovery as well as to make it more cost-effective. Chemically bound energy depends on the organic content of wastewater, which is conventionally estimated through its chemical oxygen demand (COD). Every kilogram of COD embodies 3.49 kWh, which—with a COD load of 110–120 g per person per day—leads to a theoretical maximum potential of chemically bound energy of 400 Wh per person per day [13]. How much of it can be recovered, and at what cost, entirely depends on local conditions as well as on the technologies that are (or may be) employed. More energy can be recovered if the organic content is more concentrated; that is, systems that allow for a separate collection of blackwater are more responsive to this goal.

How much of this energy can be recovered, as well as at what cost, depends on (1) site-specific conditions; (2) the water system design; and (3) the available technologies. As to (1), some sites may be better suited to allow for energy recovery than others: higher systems can create a larger potential for exploiting potential energy; places where wastewater production follows more regular patterns may allow for a more efficient use of wastewater treatment plants because of a more stable load; etc. With regard to (2), places where blackwater, greywater, and perhaps
yellowater are collected separately are usually more manageable than those where these flows are mixed. As far as (3) is concerned, the choice of technologies—which is strongly influenced by the features sub (1) and (2)—is crucial in order to make energy recovery effective both energy- and cost-wise.

Whenever a technological, organizational, or policy choice is made with regard to energy recovery from wastewater, a number of variables should be considered. Such variables have to do with site-specific features, the final goals that are to be pursued—for example, cost-effectiveness and/or sustainability of the water cycle, which may not always be aligned—and direct as well as indirect impact of the choices being made. Such impacts should be made not only with reference to the operational costs and impacts, but also with regard to life-cycle analysis. Life-cycle analysis reveals that the amount of energy that is bound into the creation of water facilities and water distribution is about 30% of its operational life-cycle cost [20].

A review of the literature on biosolids management [27] revealed that, while agricultural land application is still the most common usage of wastewater’s organic content, a growing number of energy-related options are emerging and spreading out. Among them, the most promising are biosolids combustion and anaerobic digestion.

As far as biosolids combustion [21] is concerned, while promising for its ability to reduce volumes and the potential for energy recovery, it still poses some questions. Particularly, biosolids resulting from wastewater tend to have very low calorific power as well as high moisture and ash content. However, energy recovery from incineration can still be a viable option both to reduce energy consumption from the water system as a whole and as a means of pollution abatement.

Anaerobic digestion [19,20] refers to a wide number of different techniques: “combined carbon and ammonia oxidation, activated sludge, biological nutrient removal, aerobic digestion, anaerobic processes, lagoons, trickling filters, rotating biological contactors, fluidized beds, and biologically aerated filters to provide a comprehensive understanding of the field of biological wastewater treatment” [7].

### 3.4 Environmental Challenges

The choices that are being made on the water system design and water reuse technologies are not neutral with regard to environmental impacts. Some of them may result in reduced environmental impact—particularly if they lead to energy savings—but often they merely change the kind of environmental impact that is produced. For example, they may reduce carbon emissions while increasing the production of noncarbon GHGs, particularly methane, which may have a similar (or higher) effect on the planet’s warming. In other cases, they may remove GHGs while creating other byproducts that cannot be released into the environment without proper treatment or abatement.

The most instructive approach to measure actual environmental impacts is—again—life-cycle analysis, with reference, respectively, to wastewater treatment [16] and reclamation treatment [22].

The former shows that the highest environmental impacts from wastewater treatments are linked to energy consumption. In particular, 95% of the biogas resulting from the treatment is burned in torch, while the sludge is used largely for agricultural use (98.6%), with the remaining amount being employed for compost. The most effective ways to abate pollution, therefore, rely on electricity generation from biogas, which in turn would reduce energy demand (and carbon footprint) of the water cycle itself, although it is very unlikely that it—or significant parts thereof—may become fully self-sufficient energy-wise.

With regard to reclamation treatments, it has been found that recycling water may or may not be energy-efficient, depending on local conditions. For example, a study [22] examined two cases studies whereby energy demand from recycling was in one case higher and in the other case lower than energy demand from importing water. Desalination was the most energy-intensive water source. It should be emphasized that, as far as water recycling is concerned, distribution proved to be the most relevant source of energy demand (explaining 61%–74% of total energy demand). This suggests that (1) the more energy that can be recovered, the less environmental impact, and (2) any design measure that reduces the energy cost of collecting wastewater and distributing treated water will significantly reduce the life-cycle environmental impact of the water system.

Energy is by far the most important source of environmental impact from water recycling, so it makes sense to focus on it. Yet, two further elements should be considered. First, water quality may be a very relevant variable: the higher the expected quality of the output (and the lower the quality of the input), the more energy intensive the treatment. Therefore, where the discrimination between potable and nonpotable water is possible, it may be very meaningful to employ recycled water for nondrinking uses in order to reduce energy consumption. Second, other impacts—in terms of treatment byproducts—may derive from water recycling. Therefore, focusing on carbon, while providing a reliable proxy, is not enough as it comes to comparing not just economic costs, but also environmental costs and externalities [1].

Finally, depending on the technologies employed to achieve energy recovery from wastewater, the goal of reducing carbon emissions (through a lower production of CO₂) may come at the cost of increasing noncarbon GHGs, such as nitrous oxide (N₂O) or methane (CH₄). If not properly abated (or recycled themselves), they may result in an increased, not reduced, greenhouse effect. In fact, the greenhouse power of N₂O and CH₄ is as much as 310-fold and 21-fold of that of CO₂, respectively. This is a frequent problem with wastewater treatment plants.

In fact, the most straightforward way to reduce CO₂ emissions is reduced energy consumption, which—beyond investments in making the plants as well as the whole system more energy-efficient—may be achieved by relying on self-produced energy. However, the process of energy recovery produces byproducts at several stages. The amount of CH₄ that is produced depends mainly on the residence time and the temperature of wastewater.
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3.5 Role of Smart Regulation

In order to make the best use of existing technologies—and to reduce costs as well as environmental impact from water consumption—massive investments should be undertaken. Both from the point of view of the investment profile and from that of life-cycle environmental impacts, much depends on the conditions under which the system is designed and the degree of the investor’s confidence in the system itself. This is especially true when private capitals are involved which, as we shall see, is also the most convenient case.

Underlying this issue are many questions regarding how the water system is organized and regulated, from both a financial and an institutional perspective. In fact, in this case as well as in many others where network infrastructures are involved, institutional variables—that affect both the attractiveness of the water system for private investors and the effectiveness of the public decision-making process with regard to resource allocation and design choices—are in a way the most relevant ones. Institutions allow financing in a cost-effective way the required investments, institutions drive the criteria under which the system is designed, and institutions may prevent rent-seeking activities and misallocation of resources.

An OECD report [14] enumerates seven dimensions under which institutional gaps may hinder water-energy policy coordination, resulting in suboptimal results with regard to either water- or energy-related goals, or both. Such dimensions are:

- **Policy framework**: Different political agendas, visibility concerns, and power rivalries across ministries and agencies at a central level as well as problems from national ministries dictating vertical approaches to cross-sectoral policies that would benefit from codesign at the local level
- **Administrative roles**: Unclear and overlapping roles and responsibilities among government ministries as they relate to economic, social, and physical boundaries of water and energy flows
- **Capacity resources**: A lack and/or asymmetry of knowledge, enforcement capacity, and infrastructural resources within all levels of government
- **Funding resources**: Asymmetry of revenues and distribution of resources across ministries and levels of government
- **Informational challenge**: Data gaps and inconsistencies between and within the levels and ministries of government
- **Time frame and strategic planning**: Different schedules and deadlines occur between ministries
- **Evaluation**: Without evaluation, governance practices cannot be assessed, but very often feasibility is limited [14, p. 42]

Even under this respect, there is no clear evidence that a given setting is more effective than others are. However, institutional settings whereby liabilities are clearly allocated, regulatory choices are regarded as credible and stable over time, and externalities are properly internalized tend to outperform those that fail to meet such targets. Transparency is also important, especially in those countries where corruption is widespread.

Moreover, in several instances, water is—or may be treated as—a common-pool resource, that is, a resource that is virtually accessible to everyone (or, to be more precise, a resource such that excluding potential users is either impossible or too costly). Often, it is better to rely on bottom-up institutional arrangements to avoid the “tragedy” of growing scarcity, rather than on top-down policies. Bottom-up approaches may also make more evident the benefits (if any) of water reuse as opposed to other conventional or alternative water sources. If this is true, then Elinor Ostrom’s lesson on how to manage the commons should not be ignored [15].

One specific issue regarding water/energy management and the underlying institutional setting has to do with the nature of the relevant stakeholders. The following are particularly important: (1) the understanding of who should pay for the investment (the government, water consumers, etc.); (2) who is in charge of making investments; and (3) how the compliance between investments actually being made and projected investments/costs/financing mechanisms is assured (and *a fortiori* how the monitoring of all the activities within the water system is ensured).

In this respect, it is particularly important that a solid institutional framework is settled when water reuse comes into consideration. Among the various, water-related business opportunities, water reuse is—on average—one with low expected returns. In fact, returns on water reuse investments are expected to be below 10% in a business-as-usual scenario, and slightly above 10% when a carbon-pricing scheme is set into operation [6]. This makes the reliability of the relevant set of rules absolutely crucial: it is only by virtue of the subsequent certainty that substantial resources may be confidently invested.

Strong institutions may be useful also to address the low (although growing) confidence of public opinion in using recycled water. This can be partly offset by using recycled water for nondrinking uses, but ultimately it is fundamental that people believe that those in charge of monitoring and controlling water quality are trustworthy. A major contribution can and should come from investments in information and communication to promote the positive sides of water reuse [4,5].

3.6 Summary and Conclusions

Energy is consumed in the water cycle—particularly when water is reused—and water is a relevant input in energy production. Moreover, energy is embodied in, and can be recovered from,
wastewater. Therefore, much value can be created, and a lot can be done to increase sustainability, if water reuse technologies are employed and, more generally, if water systems are designed with attention to the two dimensions of cost-effectiveness and reduction of environmental impacts.

Many choices—particularly those regarding the preferred technologies and, more fundamentally, those related to relying on water recycling or other alternative water sources, such as desalination—depend on local, site-specific variables; for example, whether an area is urban or rural, whether abundant water is available and accessible, whether water demand and wastewater production patterns are more or less variable over time, etc. [25].

There are, however, three general features that, once the decision of recycling water has been made, have a fairly broad scope, to the point that they can be generalized.

First, the system should be designed to separate as much wastewater flows as possible. It is less costly, less energy intensive, and less environmentally harmful to treat blackwater, greywater, and yellowwater separately rather than conveying them together.

Second, and by the same token, the separation of potable and nonpotable water can provide a major contribution to the effectiveness and efficiency of the whole water system: in that case, wastewater should be treated up to a quality standard that is lower than the drinking standard, and subsequently is less costly, simpler, and less energy intensive.

Third, in order to deploy a well-functioning water system, especially if it encompasses water reuse, massive investments are needed. Resources to be invested may be either public or private—depending on the cases and social as well as political variables—but, in either case, a credible institutional framework should be set in place. This is particularly important for the kind of investments that have relatively low expected returns (such as water recycling infrastructure), and whose ability to attract capital critically depends on the credibility of the expected cash flow that would be generated by the system operation over the next decades.

A consequence of the relevance of the upfront investment vis-à-vis operational costs is that a relevant part of the energy consumption is embodied in the construction of the water system itself. The appropriate tool to assess economic as well as environmental performance of the various technological alternatives and designs is, therefore, life-cycle analysis.

References


