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Article

Integrating the Carbon and Water Footprints' Costs in the Water Framework Directive 2000/60/EC Full Water Cost Recovery Concept: Basic Principles Towards Their Reliable Calculation and Socially Just Allocation

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Abstract: This paper presents the basic principles for the integration of the water and carbon footprints cost into the resource and environmental costs respectively, taking the suggestions set by the Water Framework Directive (WFD) 2000/60/EC one step forward. WFD states that full water cost recovery (FWCR) should be based on the estimation of the three sub-costs related: direct; environmental; and resource cost. It also strongly suggests the EU Member States develop and apply effective water pricing policies to achieve FWCR. These policies must be socially just to avoid any social injustice phenomena. This is a very delicate task to handle, especially within the fragile economic conditions that the EU is facing today. Water losses play a crucial role for the FWC estimation. Water losses should not be neglected since they are one of the major "water uses" in any water supply network. A methodology is suggested to reduce water losses and the related Non Revenue Water (NRW) index. An Expert Decision Support System is proposed to assess the FWC incorporating the Water and Carbon Footprint costs.

Keywords: carbon footprint; water footprint; virtual water; full water cost; water losses

1. Introduction

The Water Framework Directive (WFD) 2000/60/EC is a very important piece of EU legislation for freshwater protection in Europe [1]. WFD obliges the EU member states to achieve good status (ecological, chemical, hydro-morphological) for all EU water bodies by 2015 using the River Basin as the main water management unit [1]. WFD 2000/60/EC requires that all EU member states must develop and apply effective water pricing policies that will guarantee the recovery of the full water cost (FWCR) [1]. The FWC includes three sub-costs: the direct cost—DC (the costs a water utility pays to provide water of sufficient quantity and appropriate quality to its customers); the environmental cost—EC (the damages due to the waterworks built and the increased water use, caused directly to the environment and indirectly to users); and the resource cost—RC (the revenue losses caused by water misallocation). The main aim is quite simple: "all water users should pay a fair price so that the full costs related to the entire process involved in the water supply chain (e.g., abstraction, supply and distribution of drinking water; collection and treatment of waste water) are recovered" [1]. The EU, recognizing the importance of climate change, has implemented quite a few policies regarding water resources management and climate change conditions such as the WFD 2000/60/EC, the drinking water directive, the floods directive, *etc*.

Water supply systems are massive consumers of energy through the water production and supply process [2]. Carbon footprint (CF) volume could be reduced by cutting down the amount of energy used throughout the entire water supply chain. As EC is related to the damages to the environment, it is directly linked to what CF stands for, since it demonstrates the environmental damages due to the infrastructure (e.g., damages caused by CO_2/greenhouse gases (GHG) emissions and their impacts to the end-users). Environmental damage cost equals the cost required to restore the environment to its original status. Water resources are not the only piece of environment associated to the environmental cost. Air is also affected due to the carbon dioxide and greenhouse gas emissions caused by the production of the infrastructure used for water supply and distribution as well as the water supply chain operations itself. RC is also directly related to different energy consuming processes (e.g., water losses in networks; revenue losses due to misallocating water to alternative uses [3]). The DC (as a sum of the annual equivalent capital costs; operating/maintenance costs; administrative/other costs) includes energy consuming activities such as the construction and use of infrastructure and materials.

There is an interrelation between carbon and water footprinting in the water supply process. Trying to reduce each footprint related to the water supply, it is crucial to apply the most appropriate methodology to reliably estimate it. Energy efficiency improvements could lead to 20–30% reduction of energy use and also to an approximate 30% reduction of a leakage that will lead to the reduction of the overall water demand [4]. This could lead, for example, the carbon emissions in Eastern Europe and Central Asia to be reduced by 50% [4]. On the other hand, the reduction of a process-related water footprint (WF) leads to energy savings which is the simplest way to adapt and mitigate climate change [4]. A major cause for energy waste is excess supply due to water leaks or due to inefficient use of water. High leakage levels are often responsible for more than 25% of the total energy consumption. When the water loss average level worldwide reaches 30%, the very same portion of energy is lost. Thus, energy consumption savings might rise to 20%–30% of the current use [2]. Due to water network complexity (hundreds of Km underground pipes with thousands customer connections) the distribution step is the most complex phase to audit, no matter the resource (energy or water) origin.

This paper reviews the state of the art research on carbon credits related to the water supply chain, its interconnection to both WF and virtual water. The final goal is to develop a solid step-by-step methodology that assesses the FWC (drinking water) incorporating the carbon and the water footprint costs to the environmental and natural resource costs respectively. Special focus is given on the carbon footprint cost related to water losses, occurring in urban water pipe networks, trying to provide a socially just answer to the questions of who should pay for them and how.

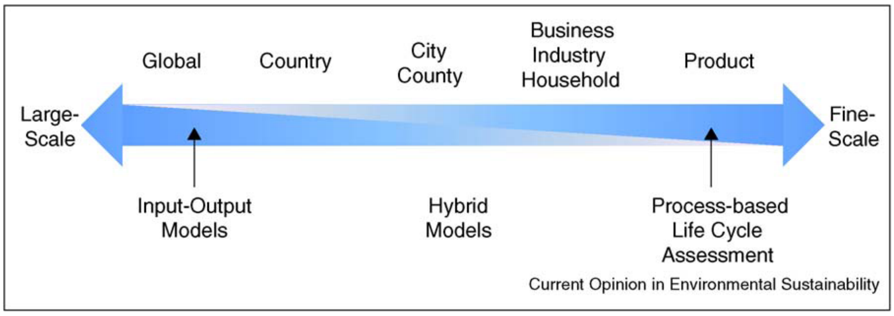
2. Carbon and Water Footprint, Virtual Water

2.1. Carbon Footprint (CF)

Carbon Footprint (CF) is defined as "the total amount of greenhouse gas (GHG) emissions directly and indirectly caused by an activity or is accumulated over the life stages of a product" [5]. To provide accurate estimations, numerous approaches have been proposed, such as basic online calculators, sophisticated life-cycle analysis or input-output-based methodologies and tools. According to Peters [6] carbon footprint can be analyzed from global to product scale using different methodologies (Figure 1).

Two basic methodologies are the most suitable to define CF, the Life-Cycle Assessment (LCA); and the top-down input-output analysis [6,7]. The combined use of these two methods is also suggested [6]. LCA is a methodological tool that applies the life cycle concept on environmental analysis of activities related to the product processes (goods/services). In practice, the methodology depends on functional unit via scale (Figure 1) [6]. All functional units should determine their CF. In fact this should be done at global, national or local level such as in a business, industry, household or process/product level [6–9].

Figure 1. Carbon footprint (CF) applications/corresponding methods across scales [6].



For drinking water supply networks, it can be concluded that: "CF is the total amount of CO_2 and other GHG, directly or indirectly emitted over the full life cycle of the water supply chain" [5,6]. The drinking water supply chain is a complex process where in its full life cycle many stakeholders are involved. Their involvement leads to various energy consuming processes.

In a national level GHG emissions are related especially to vehicles, energy used in buildings, industry, agriculture, and waste. Assuming that a water utility is an "industry" and a water supply chain is a "process/product", the most appropriate methodology to determine the water network CF is the LCA. It is the cornerstone on new thematic policies and strategies such as the Sustainable Use of Natural Resources [10]. Life Cycle Impact Assessment (LCIA) is the phase of the LCA where inventory data on inputs and outputs are translated into indicators about the water network potential impacts on the environment, human health, and the availability of natural resources [7].

Considering the separation of a company's emissions into direct and indirect a water utility GHG could be: (a) emissions from operations that are owned or controlled by the water utility; (b) emissions from the purchased or acquired recourses consumed by the utility; and (c) all other indirect emissions that occur in the value chain including both upstream and downstream emissions. The interconnection between water and energy is a subject where considerable amount of research and investigation has to be carried out. Today water is considered an energy-consuming agent [11]. Energy audit tools and the related indicators can be used to assess the amount of energy used and consumed in the water supply chain. Water losses have to be incorporated as well.

2.2. Virtual Water (VW) and Water Footprint (WF)

Virtual Water (VW) was first introduced by Allan [12,13] as the water quantity "contained" in a product or/and needed to generate this product. The meaning of VW had to do with the amount of water used to produce one unit (kilo, piec e, *etc.*) of a product or used to offer a specific service. VW was also used in relation to trade meaning that VW could be imported or exported in a country. It can be assumed that when products are exported from countries of water abundance and these products are imported in countries of water scarcity, the water resources of this country are increased [14]. Hoekstra [15] introduced the methodology to quantify VW and defined the concept of WF. He defined WF as "the volume of water necessary to produce the good and the services consumed by the inhabitants of a country" [15]. WF was actually defined as an "indicator of the use of water in relation to the population's consumption level" [16]. WF can be defined as the 'hidden' water consumed globally [17]. The difference between VW and WF is that the first one is an indicator regarding the production of goods and services, while the latter is an indicator regarding the population's consumption of these goods and services [14].

Two methods can be used to assess WF namely, the bottom-up and the top-down method [17]. The bottom-up approach can be applied for individual production processes using the methodology of life cycle assessment (LCA). The International Standardization Organization (ISO) considers the development of a new standard to provide internationally harmonized metrics for WF [18]. The proposed International Standard will deliver principles, requirements and guidelines for a WF metric of products, processes and organizations, based on the guidance of impact assessment as given in ISO 14044 [18]. The top-down approach is based on a final rather than apparent consumption assuring that water used in the production of a product is assigned to the end-product consumed. It is common to use a combination of these two methodologies. The overall picture is that for the calculation of both CF and WF common methodologies can be used depending on the functional unit. The VW balance of a country can be calculated as follows [15]:

$$\text{VW} = [\text{Use of Domestic Water Resources}] - [\text{Virtual Water Export Flows}] + [\text{Virtual Water Import Flows}] \quad (1)$$

The size of the national WF and its composition differs amongst countries [19]. The process related to the WF greatly differs compared to the WF of a country. The former is determined by four direct factors: (a) volume of consumption (related to the gross national income); (b) consumption pattern; (c) climate; and (d) agricultural practice [19]. On the other hand, a country's WF consists of: (a) the internal (the sum of the total water volume used from the domestic water resources in the country's economy minus the volume of VW export to other countries); and (b) the external (the annual volume of water resources used in other countries to produce goods and services consumed by the residents of the country concerned). Regarding the drinking water supply chain, the WF is the total volume of freshwater used for the provision of drinking water consumed by a water utility. Assuming that the supply of drinking water could be referred as a "product", its direct WF refers to water consumed in operations such as, the sedimentation or the filtration process. Indirect WF refers to water consumed in the supply chain to produce infrastructure used such as water pipes or materials purchased by the water utility. High leakage levels in a water distribution system may lead to high energy consumption due to pumping and therefore increase the maintenance level of infrastructure. This can lead to high values of CF and WF.

3. Full Water Cost Recovery Principle

The WFD 2000/60/EC introduced for the first time the Full Water Cost Recovery (FWCR) Principle, based on a very simple concept: any water volume out flowing from a natural resource has a negative impact on the resource's self cleaning potential and its water balance [1]. So, the FWC of any water volume taken from a water resource should be calculated by considering its impacts on the initial quality and quantity of this water resource. FWC includes the costs required to ensure that water of proper quality is available; the price the urban user has to pay due to the reduced opportunities left to other users; and the costs for maintaining and improving the quality and quantity of the water resource based on the environmental sustainability principles [20]. FWC consists of three sub-costs, namely Direct Cost (DC), Environmental Cost (EC) and Natural Resource Cost (RC). These sub-costs affect one another (e.g., reduction of EC means better water quality, resulting in reduced DC due to less treatment necessary in the water treatment plants). These sub-costs are dynamic sizes, as they depend on various parameters (e.g., time season, geographic region, population density, economic activity). These interconnections make the precise definition as to which factor (and to what extent) is responsible for FWCR; a very intriguing task to achieve [21].

3.1. Direct Cost—DC

DC includes the costs a water utility pays to provide water of sufficient quantity and appropriate quality to its customers [21]. DC includes the Operation/Maintenance Costs (staff, energy, chemical, stock, materials, fees/expenses to third parties); Administrative and Other Costs (management related); and Annual Equivalent Capital Costs (of new investments, depreciation of existing infrastructure). The necessary waterworks and the way the water utility operates affect the level of the DC and its components [21–23].

DC includes sub-costs affected by the network management practices. A typical example is the time and space variation of the repair and replacement costs of the network pipe, and the rate of failures occurrence. In order for the DC to be safely assessed a hierarchical analysis of the troubleshooting network parts is needed using specified models along with models determining the optimal pipe replacement time [24]. Whenever pipe replacement and preventive maintenance works take place on time, the operation and maintenance costs of the network are significantly reduced.

3.2. Environmental Cost—EC

EC expresses the damages, due to the waterworks built and the increased water use, caused directly to the environment and indirectly to users. Till now EC recovery policies were based on environmental taxes and charges related to freshwater and sewage services included in the water bills. Politicians were involved in the process leading to an irrational allocation that does not fully recover the EC involved. WFD basic principle states that the environmental damage is equal to the cost required to restore the environment to its original condition, based on the assumption that the lowest value of an environmental good is equal to the necessary costs for its protection. WFD requires that all water bodies (across the EU) must be at good ecological status by 2015 [1]. WFD requires from the EU Member States to classify all water bodies in five groups (high, good, moderate, poor and bad) according to their quality and based in their ecological and chemical characteristics. The cost for a water body to move up in the WFD classification rapidly increases as the ideal situation is approached.

The benefits gained by the good status water bodies (economic activities, *etc*.) should be integrated in the EC. EC is a dynamic rather than a static size. After its full determination and complete recovery through additional charges, EC will tend to decrease with time. DC will also decrease, as it is directly linked to the EC (this must be considered as an immediate profit). There are several methods to determine the EC level and they should be assessed. There are methods based on the analysis of environmental damages in similar cases. However, one method cannot fit all cases [24–26].

3.3. Resource Cost—RC

RC has two definitions: The first is used in regions affected by drought. There, RC equals the lost profits suffered by other users/uses when water resources exploitation rate exceeds their supplying capacity [3]. The second definition is used in many central and northern Europe countries, not facing serious water shortage problems. There RC occurs when water is not being utilized to its best use, meaning that there are alternative uses available generating higher profits [3]. RC actually expresses the revenue losses caused by water misallocation. In regions facing serious water shortage problems, it is suggested that both definitions are used and the total RC value includes both components [21].

Important factors such as the local economy characteristics and the sizes of the productive sectors should be considered forming the optimal allocation of the water available among the distinct uses based on economic criteria. The final allocation must incorporate social criteria and the strategic interests of the region. The most recent environmental management approaches of sustainability and worth-living development will be considered. The worth-living development aims at reducing in time, and not just maintaining, the cost of equal opportunity among the users and/or within the same use. In any case, RC can be defined as the gap between the existing allocation and the optimal one [21]. A water resource RC changes when its reserves and supplying capacity change by time. In the medium to long run RC tends to decrease following the way EC changes. Field data collected so far worldwide showed that the water resource opportunity cost gets higher under water scarcity conditions and decreases when the water storage is possible [21].

4. Integrating Carbon and Water Footprints in the Water Services Costs

4.1. Carbon and Water Footprints in the Water Supply Chain

Considering the interrelation between carbon and water footprint the following common aspects are addressed (Table 1). Carbon and Water footprints were not taken into consideration up to now during the FWC calculation process. The FWCR process and the pricing policy formation process should take into consideration both carbon and water footprints. Carbon footprint related cost should be included in the EC calculation process while water footprint related cost should be included in the water RC calculation process. The challenge of facing carbon and water footprint as two components highly interconnected, focusing on improving the performance of a water supply chain process, could only lead to a more sustainable environment. Improving the performance is a process which needs commitment and participation of all key stakeholders. In terms of the principles on capacity building and human resources development, the importance of leadership and commitment, the roles of stakeholders and the importance of integrating the capacity building process into the overall development of water supply and sanitation is very crucial. Better knowledge of the highly complex process of a drinking water supply life cycle could end to effective solutions customized in the characteristics of each country and the specifications and special requirements of each water utility. Researchers should focus on the effective methodological approach for the CF and WF calculations and their integration to the full water cost recovery theory according to WFD 2000/60. The water utilities pricing policies is another important aspect. Consumers should pay fair prices for water services. Water utilities should not try to recover water losses costs due to bad infrastructure conditions by applying several pricing tricks such as the fixed rate. Thus, the main aim should not only address the FWCR principle, but also the fact that all water users should pay a fair price in order the full costs related to the entire process involved in the water supply chain (e.g., abstraction, supply and distribution of drinking water; collection and treatment of waste water) to be recovered [1]. This path could only lead to a better performance of water utilities, a "socially just" pricing policy and improvements in their performance goals, such as: efficiency, effectiveness, transparency, accountability and financial as well as environmental sustainability [27].

Table 1. Basic common aspects of carbon footprint (CF) and water footprint (WF).

Category	Aspect
Definition	Similar definitions depending on the functional operations (global, country, region, city, business, industry, household, process/product level)
Methodology	Common methodological approaches depending on the functional operations (global, country, region, city, business, industry, household, process/product level)
	Best methodology for their calculation in a water supply chain is LCA approach
Standardization	Development of ISO standards for their calculation globally
Full Water Cost Principle	Both of them should be included in the FWC recovery principle as it is defined according to the WFD, by considering the definition and the analysis of the three FWC components (DC; EC; RC)
Pricing Policy	Water pricing policies should take into account both footprints
Water Losses	Reducing water losses could lead to reducing CF and WF.
Strategy	WF, reported on a product level, can be used to empower consumers to take greater responsibility for their purchasing behaviors and that this might stimulate further innovation in business
	WF is creating a capacity for change comparable to CF

4.2. Integrating Carbon Footprint (CF) in the Environmental Cost (EC)

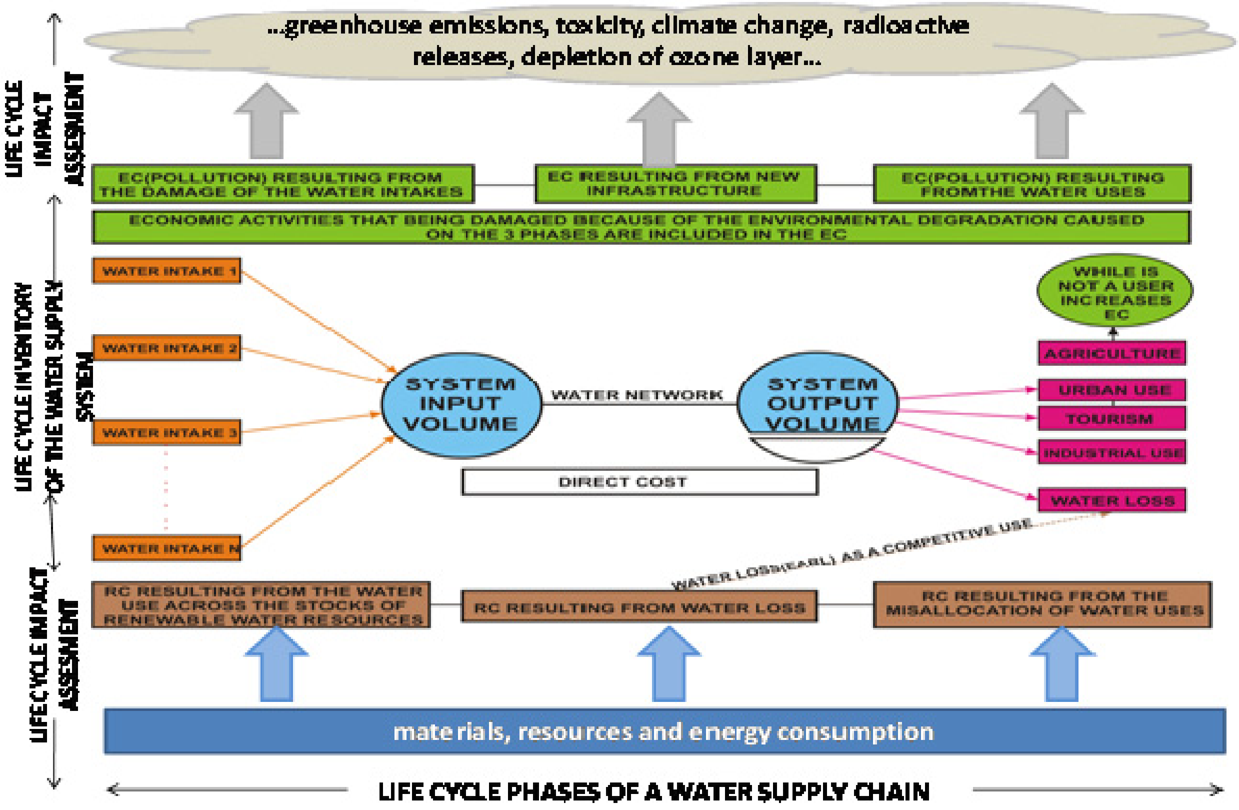
Water supply chain as a complex process includes a number of activities where large amounts of energy are used. Calculation of GHG emissions should be associated with construction, manufacture, installation, maintenance and operation considering all phases of a water supply chain life cycle. Energy consuming activities such as the construction and the use of infrastructure and materials are involved in GHG emissions. EC is directly linked with the definition of CF since it demonstrates the environmental damage due to infrastructure such as the damage caused by the emissions of CO_2 and other GHG and their effects to end users. Environmental damage is equal to the cost required so that the environment will return to its original status. Until now EC was only associated with the environmental damage caused to the water resource. The environment as a whole should be considered when talking about the EC. Therefore the authors suggest that CF should be integrated in the EC.

The water supply process uses large amounts of energy to supply water and treat wastewater and thus it is characterized by a large amount of GHG emissions. CF should be estimated during all phases of the water supply chain such as pumping, water and wastewater treatment, water distribution, *etc*. If water is obtained from a desalination plant, then the CF caused is much higher than the one caused by water abstracted from a natural water resource. The water distribution process should not be neglected since it also has a CF. Energy audits should be performed to calculate the energy needed and lost in the distribution system. The types of energy involved in the water distribution energy audit are natural energy (supplied by external sources); shaft energy (supplied by pumps); useful energy delivered to users; leakage energy losses; friction energy losses; and compensation energy (associated with internal system tanks) [12]. To assess the CF amount of a water supply and distribution system, a CF audit should be implemented.

The current carbon emissions and cost of carbon per water unit should be evaluated for water supply options new infrastructure, new treatment facilities and wastewater, and increased capacity in the distribution network. Finally, for demand management options carbon savings from a lower water demand strategy should be considered. Figure 2 shows the interconnection between the FWC assessment processes to the CF during the life cycle of a water supply system.

The CF cost allocation between the producer and the consumer should be as follows. The consumer pays his part of the CF cost proportionally to the product's production cost. The producer pays the proportion of the CF cost regarding the profit he made by selling this product. So if the production cost over profit is 80/20, then the consumer should pay 80% of the CF cost and the producer 20% of the CF cost. The same cost allocation applies for the delivery of water services.

Figure 2. Water supply system life cycle with data collection of a water network, resources and emissions followed by the impact assessment of emissions and resource use.



4.3. Integrating the Water Footprint (WF) in the Resource Cost (RC)

VW and WF are two indicators regarding the water quantity used to produce a product or service, the first one from the producer perspective and the second one from the consumer perspective. Based on the WF and VW principles, all products or services used in the water supply chain have their own amount of VW. Therefore each country water utilities can estimate the WF of their water supply systems. The WF in the drinking water system has to do with the amount of water spent to produce every product used in the water distribution system such as pipes, valves, water tanks, *etc*. The WF has to do also with the amount of water spent during the provision of the associated services such as water supply and wastewater facilities. This WF related cost should then be integrated in the water resource cost. How can the cost of a product's WF be integrated in the FWC? The answer is quite easy. During a product production process a significant amount of water is needed, taken from a water resource in the country of production. Therefore every product VW refers to the water resource used. This is how the RC can be related to the VW and the WF of a product. All products and services used in a utility water supply chain have a WF and its cost should be integrated in the RC of the natural resource where the water was taken from. To go one step further, the allocation of the WF cost becomes an issue. The consumer pays his part for the water quantity used to produce the product he is using, so that the original water resource will return to its original state. The producer pays also his part of the product WF cost regarding the profit he made by selling this product. The authors' team is finalizing solid methodologies towards CF into the EC and the WF into the RC incorporation. Relative results will be published in due time.

5. Suggested Methodology for Cost Allocation

5.1. Basic Concept

Socially just water services cost allocation is a subject undergoing a debate regarding the meaning of "social justice". WFD sets basic principles, such as FWCR, the pollutant pays principle and proportionality [1]. It is commonly accepted that consumers must pay fair prices for water services provision. It is inevitable that the fully recovered water cost including CF and WF costs will result in higher water prices. Therefore socially just water pricing policies should be implemented by the water utilities. Distribution network water losses are one of the network's uses since water losses represent in some case 50% of the water volume entering the network. Until now water losses cost has been neglected because water has been treated as a sufficient public good. Moreover, water utilities did not apply efficient and effective water losses reduction strategies. Trying to cover the Non Revenue Water cost, water utilities charged their customers with high fixed water charges. Therefore a socially just pricing policy must be applied taking into account that water is a social good in scarcity.

The basic question is: who will pay the fully recovered water cost? Stakeholders involved in the water supply chain are the water utility, the consumers and the state. In order to set social just water cost allocation, all the stakeholders involved will pay their cost part. Therefore a methodology for FWC allocation is being developed. The burden should be distributed amongst the users in the more socially just way. This is the only way the water utility can persuade the users regarding the necessity of the new pricing policy. All FWC components should be allocated according to the socially just principles set by the WFD. The proposed methodology is being explained in the following paragraphs.

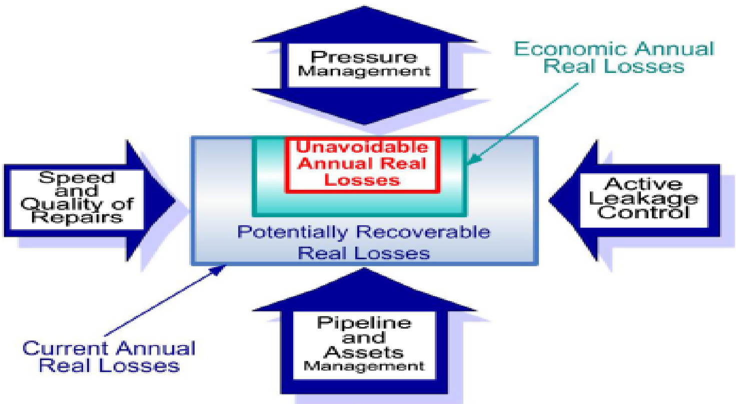
The water demand level and its spatial and time variation is a crucial issue to be used in estimating FWC components levels. The estimated unit water cost (per m^3) refers to the water volume supplied by the resource, and not to what was finally consumed [21]. The level of water costs depends on the size of the total water demand, including water losses occurring in the network (real and apparent ones including the ones occurring within the property of the consumer but not paid for). The methodology must consider any demand restrictions due to changes of the network operation/maintenance practices and differentiations of water use habits by the customers.

5.2. The Role of Water Losses and Their Cost Allocation Methodology

Water losses in urban water distribution networks worldwide are responsible for 30% average water volume being lost mainly due to leaks and breaks. In Greece this water volume goes up to 50% (national average). Water losses must be treated as an alternative water use causing expenses (intake/supply/treatment) instead of generating profits. The water utility is responsible for the largest part of water losses occurring in the network since it does not implement a water losses reduction strategy. FWCR implementation process will end up to increased water value. Therefore water losses will have increased value and every water utility must reconsider its attitude towards these losses, which will cost too much to be neglected. The real losses (leaks, breaks, tank overflows) and the ones occurring within the limits of the customer's property should be handled as a false water use, as they both represent water volume not being actually used. Additionally, as they are not being charged for, they do not produce revenues for the water utility (both volumes are parts of the Non Revenue Water—NRW—Index). Apparent losses such as water theft and metering errors, being water volume used by non authorized users but also not paid for, are also part of the NRW index. Every water distribution network suffers from Real Losses. Their existing level is called Current Annual Real Losses (CARL). As an amount of the real losses is unavoidable, they are called Unavoidable Annual Real Losses (UARL). They actually represent the minimum real losses level that can be achieved, utilizing appropriate strategies (Figure 3) [28]. UARL measured in lt/day can be estimated using the empirical expression (2) [29], where, P is the average operating pressure (m), L_m is the mains total length (km), N_c is the number of service connections and L_p is their total length (km) (up to the user's meter).

$$UARL = (18 \times L_m + 0.80 \times N_c + 25 \times L_p) \times P \tag{2}$$

Figure 3. Water losses reduction strategies [28].

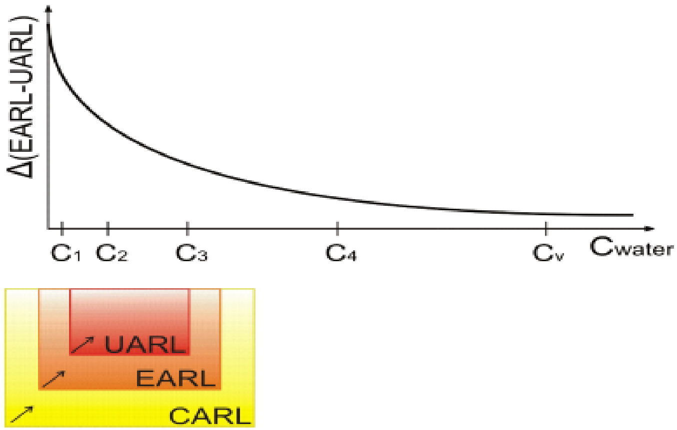


UARL is the technically achievable minimum level of real losses, while there is another level of real losses which is the economically achievable minimum level of real losses, called Economic Annual Real Losses (EARL).

The EARL level would be cost-effective to reach. The EARL form a threshold (CARL down limit) resulting from a cost-benefit analysis, as the cost to further reduce water losses exceeds the expected benefits. When the unit value of water increases, EARL and UARL tend to decrease. The difference between EARL and UARL tends to decrease as well (Figure 4).

Real losses represent water volume being lost. This water volume has a WF and a CF. This energy loss has to do with the energy dissipated in friction losses depending not only on the consumed flow rate but also on the leakage level. The energy loss associated to leakage results from the water leaking out of the network and the energy dissipated in friction losses due to the additional flow rate needed to compensate for the leakage while meeting demands [11]. Therefore real losses account also for an amount of carbon footprint related to them.

Figure 4. Moving from Economic Annual Real Losses (EARL) to Unavoidable Annual Real Losses (UARL) (in terms of necessary investment cost) [21].



Trying to best allocate the FWC to stakeholders related to the water supply process, based on the basic WFD principles, the case of the water losses and their cost allocation arises. The water utility is responsible for the largest part of the water losses occurring in the network. When the water value will be increased (after its full assessment), water utilities should reconsider their strategies towards water losses, since they will cost for more. A water losses cost allocation is proposed based on the basic WFD principles and the social justice principle:

(a) Apparent losses cost allocation

- The consumers must pay the FWC of the water losses (apparent) occurring within their property.
- The water utility must pay the rest of the apparent losses due to theft, metering inaccuracies, corrupt practices during metering, *etc*.

(b) Real losses cost allocation

- The consumers pay the FWC of a minimum accepted water losses level (UARL max level equals 5% of the System Input Volume), in return for having access to water (opportunity cost).
- When the real losses exceed the unavoidable real losses level, then both customers and water utility pays the remaining part of the UARL FWC, according to the water volume each one uses. The same should be the case regarding the FWC of the difference EARL-UARL.
- The water utility must pay the FWC of the difference CARL-EARL, as a penalty for the network's poor operating performance level.
- The State should pay its part of the above costs (in the form of grants to the water utilities) if involved in the construction and initial management of the network infrastructure. The size of the State's contribution should be discussed (negotiated) with the water utility.

(c) Investments cost allocation

When the water utility invests to reduce the CARL level to the EARL one, FWC components will be reduced due to the reduced water demand. These investment costs should be allocated as following:

- The water utility must directly pay the biggest part of these costs. Until now utilities usually ask customers to recover these costs by including specific charges in the water tariffs (expansion charges).
- FWC will be reduced as a result of the reduced water demand level and of the minimized water losses. Then the water prices will be reduced and the customers should cover a part of these costs.
- Finally, the State should pay its part (in the form of grants to the water utilities) if involved in the construction and initial management of the network infrastructure. The size of the State's contribution should be discussed (negotiated) with the water utility.

(d) CF and WF water losses cost allocation

As previously explained the FWC will include CF and WF costs. The proposed cost allocation for CF and WF costs is as follows:

- Regarding the CF cost: The consumer pays his part of the CF cost proportionally to the product's production cost. The producer pays the proportion of the CF cost regarding the profit he made by selling this product. So if the production cost over profit is 80/20, then the consumer should pay 80% of the CF cost and the producer 20% of the CF cost.
- Regarding the WF cost: The consumer pays his part for the water quantity used to produce the product he is using (or the water quantity the consumer is using), so that the original water resource will return to its original state. The producer pays also his part of the product WF cost regarding the profit he made by selling this product.

5.3. The Suggested Step-by-Step Methodology for the NRW Index Reduction

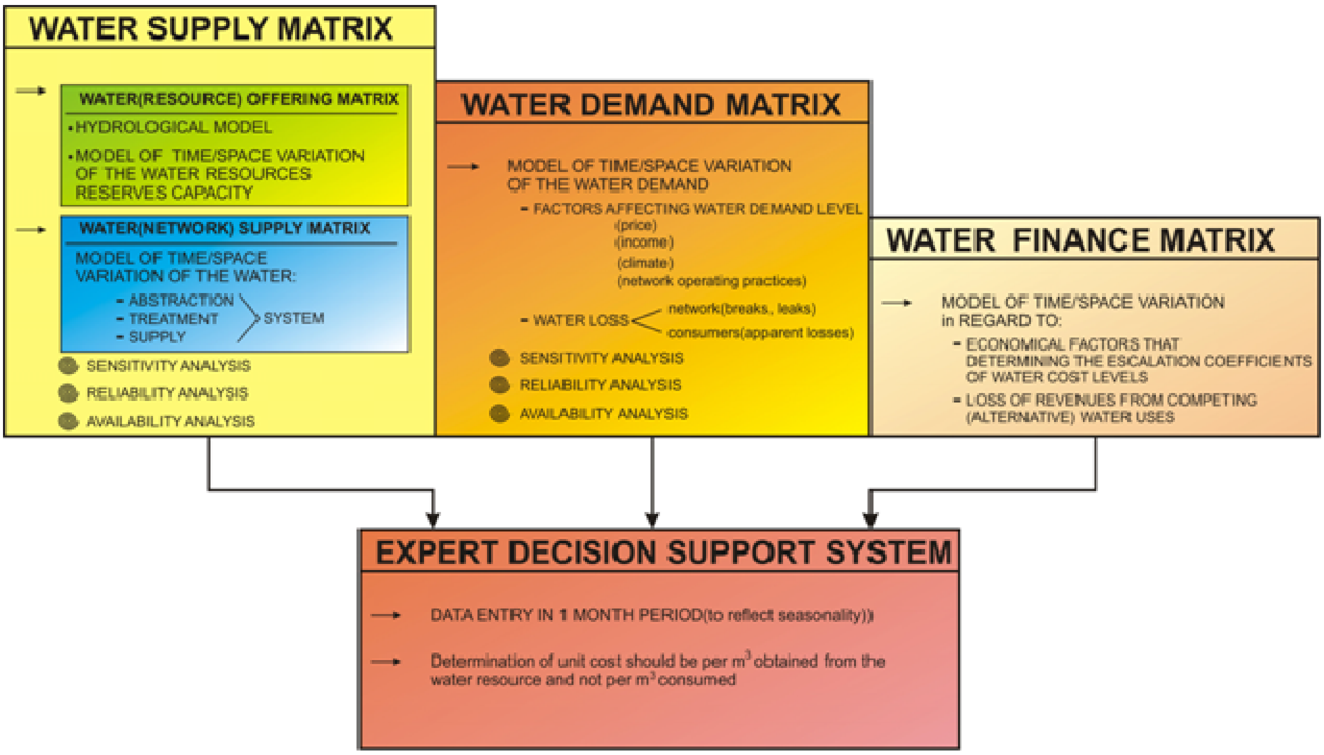
To calculate the FWC of water supply, several factors related to the water resource, water users and those responsible of pollution must be taken into account. FWC components affect one another while being affected also by other common factors. Kanakoudis *et al.* [21] propose that FWC estimation should take into account the spatial and time variation of its components. The latter depends on the spatial/temporal variation of: (a) the users' characteristics (size; income; water use pattern; seasonal change); (b) the water resources (supplying capacity; hydraulic cooperation; pollution); and the figures of the economy defining the price adjustment factors to avoid economic obsolescence. Consequently the FWC estimation should be done: (a) by using a specific area size (river basin district-RBD); (b) by using a specific time period (following the hydrological models and scenarios regarding the change of economic indicators); and (c) for each user type (domestic; public; social; water losses; industrial) checking the sensitivity of the model towards its parameters. The calculation should include the Damage/Risk Avoidance Cost at technical and economic level [21].

Considering all the above, several models must work together to calculate the FWC components. These models should forecast the space-time variation of specific parameters, such as:

- The 'water supply matrix' will consist of the 'water (resource) offering matrix' and the 'water (network) supply matrix'. The first will consist of the hydrological model (e.g., a hydrological model to assess the inflow to the resource; a ground or surface water hydrology model to assess what the water resource can offer; a water-intake works operation model) and the model of the spatial and temporal variation of the water resources reserves capacity. The ‘water (network) supply matrix’ will consist of the model of the spatial and temporal variation of the water abstraction, treatment and supply system. For each component of this system the results of a sensitivity, reliability and availability analysis will be also taken into account. The water quality characteristics of each water resource can be also included in the ‘water (resource) offering matrix’ (Figure 5).

- The ‘water demand matrix’ will result from a model of spatial and temporal variation of: (a) the water demand pattern for each type of use/user; (b) the factors affecting the level of demand (e.g., income, price, race, religion, size of property); and (c) external factors (e.g., climate, network operation and maintenance practices, water losses levels). For each part of this system the results of an analysis of sensitivity, reliability and availability will be also taken into consideration (Figure 5).
- The ‘water finance matrix’ will result from a model of spatial and temporal variation regarding economical factors defining the water price adjustment to avoid economic obsolescence, and the profit levels of the alternative (competing) water uses (revenue losses) (Figure 5).

Figure 5. The suggested Expert Decision Support System (EDSS) connecting platform [21].



The final outcome, currently being developed by the authors, will form an Expert Decision Support System (EDSS) (Figure 5), where data input will take place in a monthly step, to record any time variations. As the price of the water is expected to increase obeying a FWC recovery policy, the EARL threshold will tend to decrease approaching the UARL level (the costs of the measures to reduce the water losses level will tend to be more cost-effective). Additionally, by reducing the water losses level, the related DC and RC will also decrease, as less water will need to outflow from the water resource to cover the water demands. The same may result with the EC level, in case the quality of the water in a water resource depends on its reserves. The decreased level of the FWC components will result in reduced water prices. The water-use level is expected to be affected, depending on the water price elasticity index. If the water demand will increase, water prices will increase as well, forcing water use to decrease. It is expected that in the long run the entire system will balance to an almost-constant unit price of water, or a smooth increase trend following the increased demand.

Reduced water losses will result in less water needs to be taken from the water resources to meet the water demands. This is the effect of a pressure management strategy. An action plan regarding the implementation of a water losses reduction strategy based on pressure management is proposed (applicable also for any water losses reduction strategy adopted):

1. Assess the system's supplying capacity (water resources reserves level; water intake works capacity; water aqueducts carrying capacity).
2. Monitor—using a SCADA—the entire system (water resources; water network; water storage tanks).
3. Develop the entire system's simulation model (use data from the SCADA to calibrate/validate it).
4. Estimate the UARL level based on the network's current operating pressure (using Equation (1)).
5. Form the Water Balance of the water distribution network and assess the NRW level.
6. Estimate the EARL level, based on the existing water pricing policy.
7. Determine the water demand level.
8. Estimate the FWC components (DC, EC and RC including CF and WF costs) based on the current total water demand (ex-ante evaluation process). Calculate the FWC level.
9. Determine the new (higher) water price levels based on the current FWC levels (ex-ante evaluation process). These higher price levels will result in reduced total actual water use due to the water-price oriented elasticity of demand (as the price gets higher, the demand decreases).
10. Determine the new (lower) water demand level and the new (lower) EARL level based on the new (higher) water prices set (ex-ante evaluation process).
11. Pinpoint the crucial network points for pressure management (e.g., zoning through PRVs) or even DMAs formation. Apply the most cost-effective strategy (thorough cost-benefit analysis).
12. Estimate the new (lower) UARL/NRW levels based on the network's reduced operating pressure.
13. Estimate the new (reduced) water demand level due to the higher price levels and reduced losses.
14. Estimate the new (lower) DC, EC, RC levels (including CF and WF costs) due to the reduced water demand (ex-post evaluation process). Calculate the new (lower) FWC level.
15. Determine the new (lower) water price levels based on the new (lower) FWC. These lower price levels will force total water use to increase due to the water-price oriented elasticity of demand.
16. Determine the (increased) EARL levels based on the new (reduced) water prices set.
17. Pinpoint the new crucial points in the network to act. Implement the most cost-effective solution.
18. Determine the new UARL/NRW levels due to the reduced water losses due to the interventions.
19. Estimate the new increased water demand because of the new reduced water prices.
20. Repeat steps 8-19. The system will eventually balance to its 'sustainability level'. UARL will then be minimized, EARL will tend to be equal to UARL and CARL will tend to be equal to

EARL. The whole process should be repeated based on a water tariffs re-adjustment period (3–5 years).

6. Conclusions

The basic principles to incorporate the WF and the CF to the FWC assessment process considering the socially just cost allocation, are presented in this paper. VW, WF and CF definitions are given and the basic methodological approaches to estimating them are reviewed. Then, FWC sub-costs are analyzed namely DC, EC and RC. All depend on various parameters such as time, season, geographic region, population density, economic activity. This interconnection makes them dynamic sizes and the FWC estimation process a very challenging task. Water demand level and its spatial/temporal variation are critical factors for FWC components estimation. The determination of the water unit cost should refer to the water volume supplied by the resource, and not to what was finally consumed. Water losses should be considered as the largest water consumer of the network since they represent 50% of the SIV in some cases. Water losses do not provide revenues to the water utility and they are part of the NRW index. The authors suggest a 20-step methodology to reduce the NRW index of a water distribution network. A water losses cost allocation methodology is also presented by the authors based on the principle of social justice, including CF and WF costs. All stakeholders (the consumers, the utility and the state) should pay their FWC part.

The integration of the WF and the CF costs into the products costs has a long tradition in life cycle analysis, impact assessment and economic analyses [7,8,10,14,16,17]. Up to now the FWC calculation process (as required by the WFD) has not taken into consideration the impact of the CF and the WF of the products used in the water supply chain and of the water supply, distribution and wastewater treatment processes. The innovative part of this work is the authors' suggestion for the incorporation of WF and CF costs in the FWC. VW and WF cost refers to cost part of the water used to produce the product or service involved in the water supply chain. Therefore the stakeholders should pay for the WF to maintain the water resources (from which water is taken to produce the product/service) in good ecological status (both in quality and in quantity). Therefore WF should be incorporated into the RC. CF has to do with gas emissions from the production of the products used in the water supply chain and the emissions generated from all the water supply chain phases (water abstraction, desalination, pumping, water distribution, water and wastewater treatment plants, *etc*.) An important amount of gas emissions are generated during the water distribution process from the pumping station, the leakage and the friction losses. This concept is already being studied by researchers [11] by performing energy audits and establishing energy performance indicators. EC should incorporate CF since there is a cost involved in the restoration of the environment because of the gas emissions.

Finally, the whole FWCR process should refer to a specific space area. Following the guidelines set by the WFD, this process should take place within the limits of a River Basin District (RBD). To evaluate both the EC and the RC related to a water resource, it is important to determine the area where the environmental impact takes place [30]. Since within one RBD, more than one water utility operates, it is proposed that the contribution of each water utility be calculated in percentages of environmental damage and depletion of natural reserves of the whole RBD.

References

1. Official Journal of the European Communities. Directive 2000/60/EC of the EP & of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. 2000, L327:1–L327:72. Available online: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri =OJ:L:2000:327:0001:0072:en:pdf (accessed on 1 December 2011).
2. Feldman, M. Aspects of energy efficiency in water supply systems. In *CD-Proceedings of the International Conference on Water Loss*, IWA, Cape Town, South Africa, 26–30 April 2009.
3. CIS-WG2.6. Economics and the environment. The implementation challenge of the water framework directive. A guidance document. In *Common Implementation Strategy, Working Group 2.7-WATECO*; France and the European Commission: Brussels, Belgium, 2002.
4. IWA. Task Force on Water Utility Efficiency in Low and Middle Income Countries (LAMIC TF). Increasing Energy Efficiency of Water Supply—How to introduce carbon credits to the water sector? Concept Note. 2009.
5. Wiedmann, T.; Minx, J. A Definition of "Carbon Footprint". In *Ecological Economics Research Trends*; Pertsova, C.C., Ed.; Nova Science Publishers: Hauppauge, NY, USA, 2008.
6. Peters, G.P. Carbon footprints and embodied carbon at multiple scales. *Curr. Opin. Environ. Sustain.* **2010**, *2*, 245–250.
7. JRC European Commission. *European Platform on Life Cycle Assessment*; Newsletter/info Update No.14; JRC European Commission: Brussels, Belgium, 2010.
8. Hertwich, E.G.; Peters, G.P. Carbon footprint of nations: A global, trade-linked analysis. *Environ. Sci. Technol.* **2009**, *43*, 6414–6420.
9. *Corporate Value Chain (Scope 3)—Accounting and Reporting Standard Supplement to the GHG Protocol—Corporate Accounting and Reporting Standard—Draft for Stakeholder Review*; World Resources Institute & World Business Council for Sustainable Development: Washington, DC, USA, 2010.
10. European Platform on Life Cycle Assessment European Commission. *Carbon Footprint—What it is and How to Measure It*; European Commission: Brussels, Belgium, 2011.
11. Cabrera, E.M.; Pardo, M.A.; Cobacho, R.; Cabrera, E., Jr. Energy audit of water networks. *Water Resour. Plan. Manag.* **2010**, *136*, 669–677.
12. Allan, J.A. Fortunately there are substitutes for water otherwise our hydro-political futures would be impossible. In *ODA, Priorities for Water Resources Allocation and Management*; ODA: London, UK, 1993.
13. Allan, J.A. Overall perspectives on countries and regions. In *Water in the Arab World: Perspectives and Prognoses*; Rogers, P., Lydon, P., Eds.; Harvard University Press: Cambridge, UK, 1994.
14. Velazquez, E.; Madrid, C.; Beltran, M.J. Rethinking the concepts of virtual water and water footprint in relation to the production-consumption binomial and the water-energy nexus. *Water Resour. Manag.* **2011**, *25*, 743–761.
15. Hoekstra, A.Y. Virtual water: An introduction. Virtual water trade. In *Proceedings of the International Expert Meeting on Virtual Water Trade*; Values of Water Research Report Series no 12. IHE: Delft, The Netherlands, 12–13 December 2003.

16. Chapagain, A.K.; Hoekstra, A.Y. Water footprint of nations. In *Value of Water Research Report Series 16*; UNESCO-IHE, Institute of Water Education: Delft, The Netherlands, 2004.
17. Feng K.; Hubacek, K.; Minx, J.; Siu, Y.L.; Chapagain, A.; Yu, Y.; Guan, D.; Barrett, J. Spatially explicit analysis of water footprints in the UK. *Water* **2011**, *3*, 47–63.
18. ISO. *GHG Schemes Addressing Climate Change—How ISO Standards Help*; ISO: Geneva, Switzerland, 2010.
19. Hoekstra, A.Y.; Chapagain, A.K. Water footprints of nations: Water use by people as a function of their consumption pattern. *Water Resour. Manag.* **2007**, *21*, 35–48.
20. WaterStrategyMan. Deliverable 7—Available Methods for Estimating Water Supply, Resource and Environmental Costs. The WaterStrategyMan Project. 2002.
21. Kanakoudis, V.; Gonelas K.; Tolikas D. Basic principles for urban water value assessment and price setting towards its full cost recovery-pinpointing the role of the water losses. *Water Supply Res. Technol. AQUA* **2011**, *60*, 27–39.
22. Kanakoudis, V. Vulnerability based management of water resources systems. *Hydroinformatics* **2004**, *6*, 133–156.
23. Griffin, R. Effective water pricing. *Am. Water Resour. Assoc.* **2001**, *37*, 1335–1347.
24. Pielen, B.; Interwies, E. The economic analysis according to the WFD—Status of Implementation. An international exchange of experience. In *Proceedings of the Ecologic Institute for International and European Environmental Policy*, Berlin, Germany, 22–23 April 2004.
25. Common Implementation Strategy Working Group 2B: Drafting Group ECO1. Information Sheet on Assessment of the Recovery of Costs for Water Services for the 2004 River Basin Characterization Report (Article 9), 2004.
26. Görlach, B.; Interwies, E. Economic valuation of environmental and resource costs: The case of Germany. Presented at the *Ecologic-Institute for International and European Environmental Policy*, Berlin, Germany, August 2005.
27. United Nations. The Millennium Development Goals Report; United Nations: New York, NY, USA, 2006.
28. Farley, M.; Trow, S. *Losses in Water Distribution Networks—A practitioner's Guide to Assessment, Monitoring and Control*; IWA Publishing: London, UK, 2003.
29. Lambert, A.O.; Brown, T.G.; Takizawa, M.; Weimer, D. A review of performance indicators for real losses from water supply systems. *Water Supply Res. Technol. AQUA* **1999**, *48*, 227–237.
30. WWF. Water pricing and the recovery of the costs of water services. In *WFD Economics Capacity Building Seminar*, Brussels, Belgium, 2006.