Meso-level eco-efficiency indicators to assess technologies and their uptake in water use sectors

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Executive summary

The scope of the EcoWater project is the integrated assessment of the environmental impacts and the value added to a specific product or service from the use of water. The analysis is targeted on a meso-level that encompasses the water supply and water use chains and entails the consideration of the interrelations among the heterogeneous actors.

This document presents a methodological approach for the eco-efficiency assessment of meso-level water use systems. The main objective is the establishment of a homogeneous approach for assessing the system-wide eco-efficiency improvements (or deteriorations) from innovative technologies, applicable to different water use systems, using eco-efficiency indicators.

The document is structured in three main sections. The first section provides an overview of the meso-level water use systems analysed and the principles of the eco-efficiency assessment methodology adopted. In particular, this section is focused on various sustainability issues linked to the water systems and analyses the specific issues in the meso-level water use systems, while the objectives, main components and phases of the eco-efficiency assessment methodology are presented in brief.

The second section presents the methodological approach, following the phases of the eco-efficiency assessment. It is structured as follows:

- Section 2.1 presents the phases of the eco-efficiency assessment;
- Section 2.2 discusses the goal and scope definition phase;
- Section 2.3 presents the steps for the environmental assessment of the system;
- Section 2.4 analyses the approach followed for the value assessment of the system;
- Section 2.5 presents the eco-efficiency quantification phase and the definition of the relevant eco-efficiency indicators.

The final section summarises the special methodological issues as pointed out through the implementation of the approach to several sectors (e.g. agricultural, urban and industrial Case Studies) in the EcoWater Project.

Contents

1 The meso-level water use system

In a typical water use system, freshwater is abstracted from a source (surface water or groundwater), purified and distributed to different water uses (domestic, industrial, agricultural, etc.). Each use consumes water of a specific quantity and quality, along with other resources (energy, raw materials, etc.), for the production of one or more products/goods or/and the provision of one or more services. Wastewater from each use is collected and treated before being disposed into the environment. Various sustainability issues are linked to a water system.

1.1 Water allocation issue

A typical issue, arising in systems with competitive use sectors, is the **allocation of water** among the uses, by fulfilling the demand in an optimal way (Figure 1). Optimization may refer to the minimization of the resource deficit (in water scarcity conditions) or the cost related to the use of the resource (e.g. the cost for water abstraction and distribution). Methodologies that are used to analyse this type of issues are based on resource balance concepts (Manoli, et al., 2005) and network optimization algorithms (Manoli, et al., 2001).

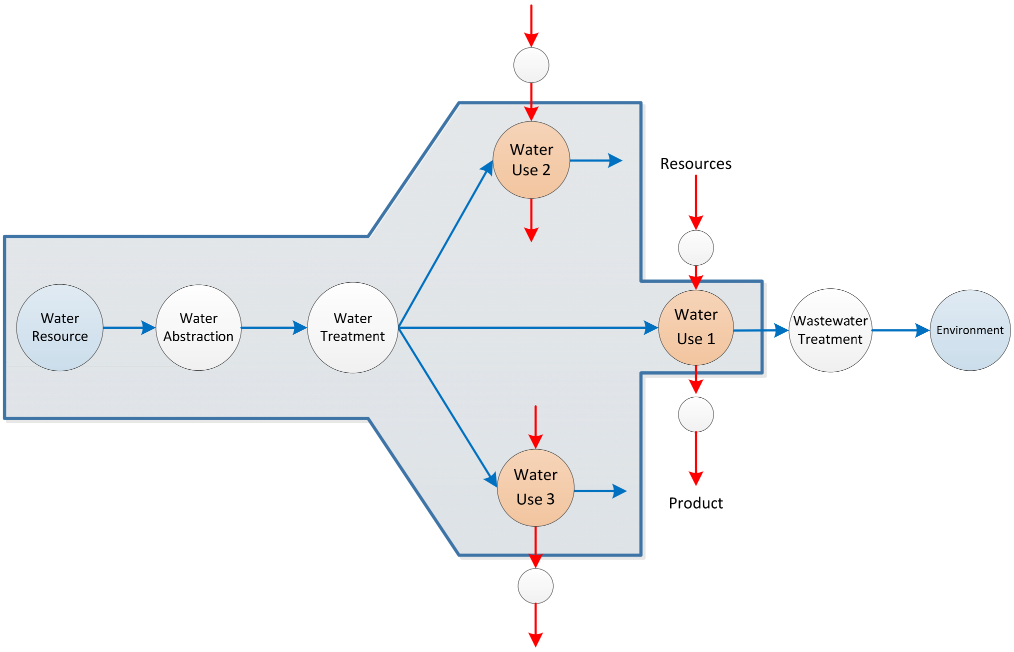

Figure 1 Water allocation to different uses

1.2 Resource efficiency issue

A common sustainability issue arising in production systems is the efficient use of resources for providing goods or services. **Resource efficiency** aims at minimizing the use of the required resources while reducing the impacts on the environment (Jonsen, 2013). Such systems are usually analysed by Life Cycle Impact Assessment (ISO, 1997; ISO, 2006; JRC, 2010; JRC, 2011) and Life Cycle Cost Analysis (Langdon, 2007) methodologies that focus on the production chain of the examined good or service, encompassing the resources required in the production processes as well as the final product. A typical example of such a system is presented in Figure 2.

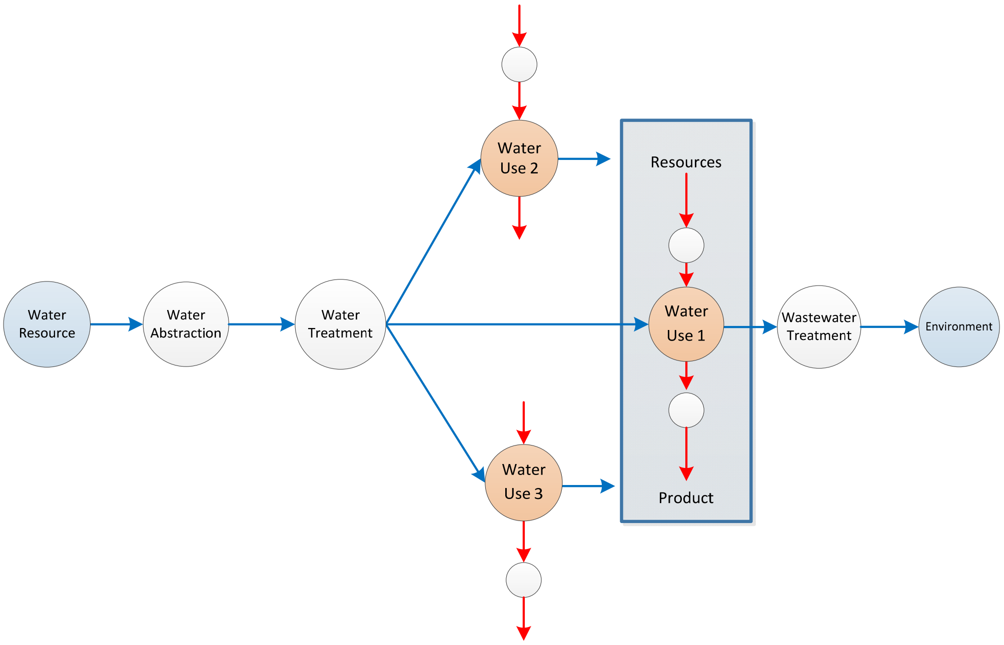

Figure 2 Efficient use of resources in a water use system

1.3 Meso-level eco-efficiency issue

The focus of the EcoWater project is on the identification and assessment of **eco-innovative technologies** that contribute to the eco-efficient use of resources such as water. **Eco-efficiency** focuses on attaining economic and environmental progress through efficient use of resources and lower environmental impacts (UN-ESCAP, 2009; O'Brien, et al., 2011). Thus, eco-efficiency is a more general expression of the concepts of resource efficiency (minimizing the resources used in producing a unit of output) and resource productivity (the efficiency of economic activities in generating added value from the use of resources).

The system presented under the EcoWater scope is a **meso-level** water use system (Dopfer, et al., 2004) that combines the typical water supply chain with the corresponding water use chain (Figure 3). It incorporates a specific water use with all the processes needed to render the water suitable (both qualitatively and quantitatively) for this use, and the treatment and discharge of the generated effluents to the environment. It is not limited to the production chain of a specific enterprise or firm, but it considers the whole water cycle of the analysed system from abstraction to disposal.

The economic analysis of the meso-level water use system also entails the consideration of the interdependencies and the socio-economic interactions of all the heterogeneous actors involved in the water supply and production chain. It also involves the sharing of resources, services and by-products among the actors (symbiosis) in order to add value and reduce costs. As a result, the meso-level water use system has a third significant component, the water value chain, as presented in Figure 3.

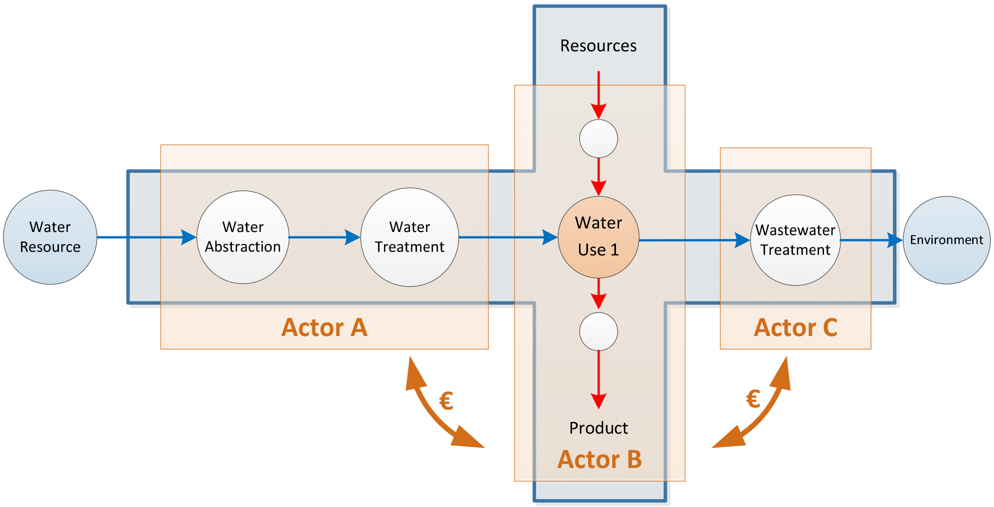

Figure 3 The meso-level water use system

2 Methodological approach

2.1 Eco-efficiency assessment

Eco-efficiency assessment is a quantitative tool which enables the study of the environmental impacts of a product or service system along with its value. Eco-efficiency brings together the two eco-dimensions of economy and ecology to relate product or service value creation to environmental impact (Young, 2001).

Within eco-efficiency assessment, **environmental impacts** are assessed using a Life Cycle Assessment (LCA) approach. Consequently, eco-efficiency assessment shares many important principles and approaches with LCA, such as life cycle perspective, functional unit, life-cycle inventory and life cycle impact assessment (ISO, 2006). The **value** of the product or service system may be chosen to reflect its resource, production, delivery or use efficiency, or a combination of these (ISO, 2012).

Eco-efficiency assessment comprises five phases, as illustrated in Figure 4:

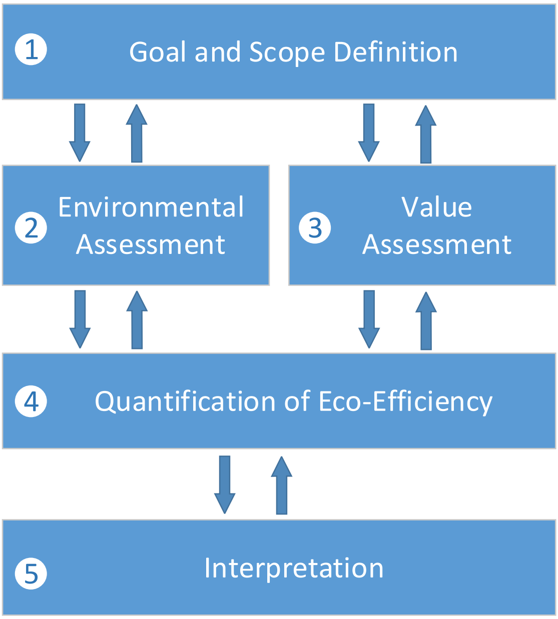

Figure 4 Phases of an eco-efficiency assessment (ISO, 2012)

1. **Goal and scope definition**: The purpose of the eco-efficiency assessment, the intended use of the results and the targeted audiences are described during the goal definition. The scope definition includes the identification of the system boundaries and the specification of the functional unit, which defines what, precisely, is being studied and quantifies the performance characteristics of the system.
2. **Environmental assessment**: It is based on a life cycle approach and consists of: i) the **Life Cycle Inventory (LCI)** analysis, where an inventory of relevant resource inputs and emissions into the environment is compiled, and ii) the **Life Cycle Impact Assessment (LCIA)** where the potential environmental impacts associated with identified inputs and emissions are identified and evaluated.

3. **Value assessment**: The value of the system is assessed considering the full life cycle of the product or service system. The value is usually expressed in monetary terms (costs, price, willingness to pay, added value, profit, etc.).
4. **Quantification of eco-efficiency**: The eco-efficiency results are determined in this phase, by relating the results of the environmental assessment to the results of the value assessment, according to the goal and scope definition. Measurement of eco-efficiency typically refers to the "eco-efficiency equation" shown in Figure 5. The numerator is the benefit (added value) provided by the product or service and the denominator is the environmental impacts (costs) associated with that product or service.
5. **Interpretation**: Comprises the identification of significant issues based on the results of the environmental and value assessment phases and the formulation of conclusions and recommendations, according to the goal and scope of the study. Eco-efficiency is progressively improved via a process of stepwise enhancement of the system value and/or reduction of the negative environmental impacts (Figure 5).

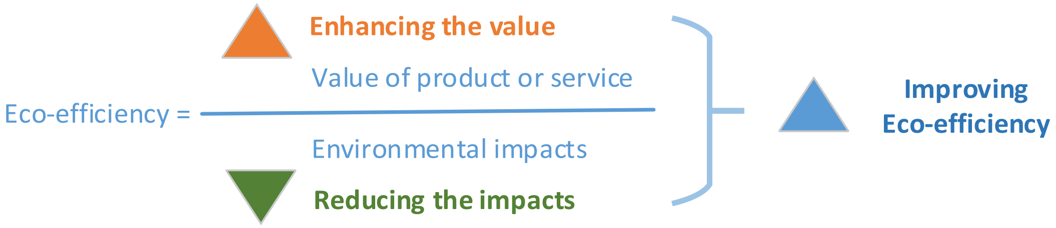

Figure 5 The eco-efficiency "equation"

2.2 Goal and scope definition

The overall goal of the analysis has been defined in Section 1.3. It concerns the integrated assessment of the environmental impacts and the value added from water use to a specific product or service in a meso-level water use system. However, the boundaries and the special characteristics of the meso-level system as well as the functional unit have to be identified.

2.2.1 System boundaries

A generic system, which models the actual meso-level water use system, is presented in Figure 6. The system is represented as a network of unit processes. Each **process** represents an activity, implementing one or more **technologies**, where generic **materials** (water, raw materials, energy and other supplementary resources) are processed and transformed into other materials, while releasing **emissions** to the **environment** (air, land, water) or into the system water flow.

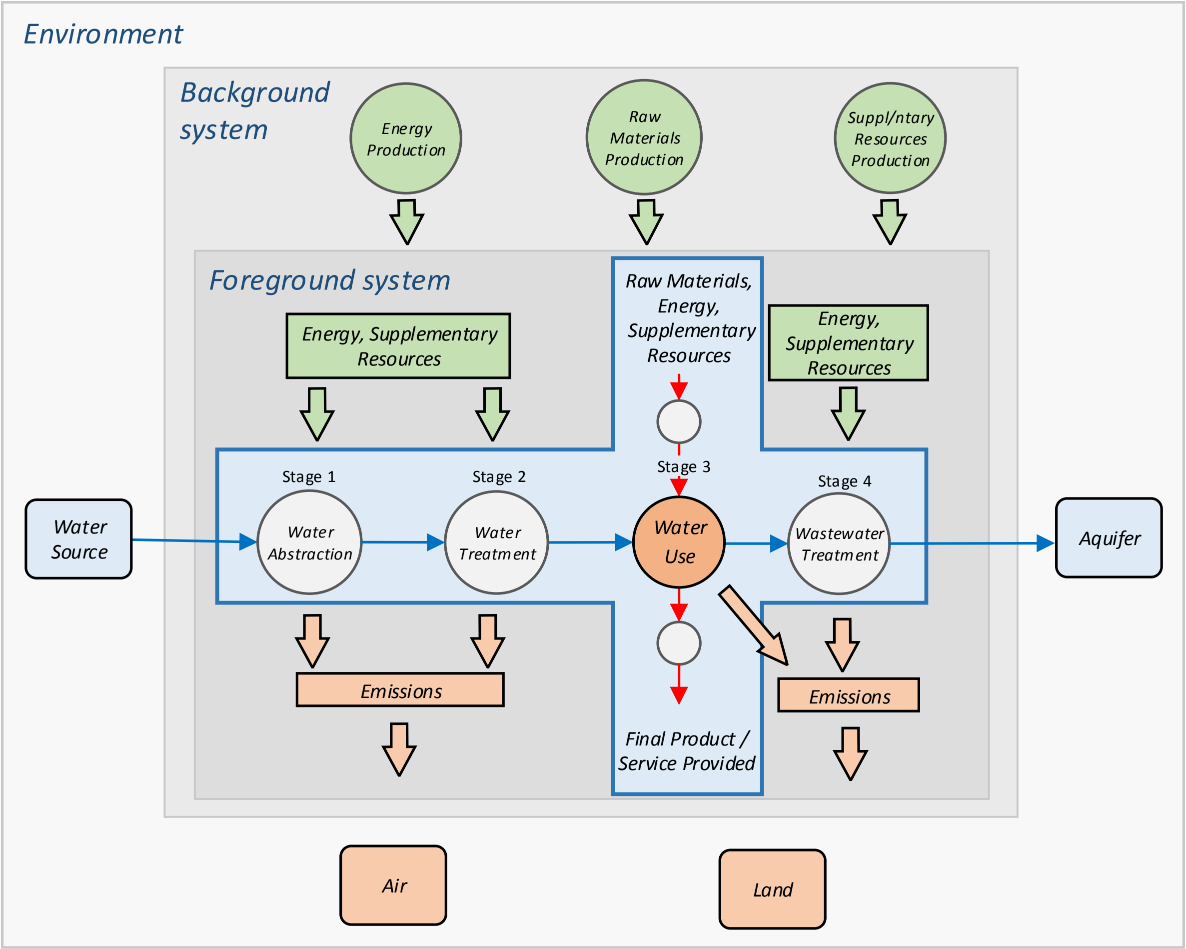

Figure 6 The generic meso-level water use system

An important element in a life cycle approach is the distinction between "foreground" and "background" systems:

- The set of processes whose selection or mode of operation is affected directly by decisions based on the study defines the **foreground system**.
- The **background system** includes all other activities and is that which delivers energy and materials to the foreground system, usually via a homogeneous market so that individual plants and operations normally cannot be identified.

As a general rule, case-specific primary data are used to describe the foreground processes, while more generic information is used for background processes (Guinée, et al., 2001).

The boundaries of the foreground system encompass all the processes related to the water supply and the water use chains and can be grouped into four generic **stages**, as depicted in Figure 6 and analysed in Table 1.

Table 1 Generic stages in a meso-level water use system

No	Name	Description
1	Water Abstraction	Processes related to the abstraction of water from the environment and the distribution to the users
2	Water Treatment	Processes related the treatment of water according to the quality standards of the users
3	Water Use	Processes related to the production of goods or services
4	Wastewater Treatment	Processes related to the treatment of wastewater before disposing to the environment

2.2.2 System area and clusters

The EcoWater system maps a geographical area and therefore it has spatial dimensions. It may also have **clusters** of water use types. Each cluster has the same water use profile (i.e. technology, socio-economic characteristics etc.) and corresponds to the production of a unique product or service (in a multi-product/multi-service system). Typical cluster definitions as well as representative examples in various water use sectors are presented in Table 2.

Table 2 Definition of potential clusters in different water use sectors

Sector	Cluster definition	Examples
Agricultural	Specific crop produced in a specific district	Maize production in pressure district Olive production in gravity district
Industrial	Specific production line	Milk production in dairy Yogurt production in dairy
Urban	Consumers of a specific profile	High income consumers Low income consumers

2.2.3 Functional unit

The definition of the **functional unit** or performance characteristics is the foundation of an LCA, because the functional unit sets the scale for comparison of two or more products or services delivered to the consumers (JRC, 2010; ISO, 2006). The main purpose for a functional unit is to provide a reference to which results are normalized and compared.

Possible functional units for a meso-level water use system are:

1. One unit of product or one unit of service delivered; and
2. One unit (e.g. m^3) of water used.

In product oriented systems, the functional unit in the first approach corresponds to one unit of each product, while in urban systems the functional unit corresponds to one consumer being served for a certain time period, as it defines the quantity and quality of the service provided by the supplied water. Examples of product functional units, in various water use sectors, are presented in Table 3.

Table 3 Examples of product functional units in different water use sectors

Sector	Functional unit
Agricultural	One tonne of maize production One tonne of olive production
Industrial	One m^3 of milk production One tonne of yogurt production
Urban	One high income consumer served for one year with a certain service quality, e.g. reliability, pressure, flow rate, temperature, water quality One low income consumer served for one year with a certain service quality

It should be noted that, in a multi-product water use system, the adoption of one unit of a specific product as a functional unit is only meaningful when examining a specific cluster and not the entire system.

2.3 Environmental assessment

The environmental assessment concerns the evaluation of the environmental impacts and follows the main stages of the typical LCA (life cycle inventory analysis and life cycle impact assessment) as described in ISO (2006).

2.3.1 Inventory analysis

Life cycle inventory (LCI) analysis involves creating an inventory of flows entering and leaving every process in the foreground system, i.e. the system within the defined system boundaries. Inventory flows include inputs and outputs of the generic “materials” presented in Table 4.

Table 4 Material types in the meso-level water use system

Material Type	Description
Water	Water service related materials (fresh water, wastewater).
Resources	Various resources used in the processes of the water supply chain or in the production chain (energy, raw materials, chemicals, etc.)
Emissions	Emissions generated from the processes of both chains and released to the environment
Products/Services	The main outputs of the water use stage
By-products	Produced by the processes of both chains

The notation used to represent the flows of the above materials is presented in Figure 7 and described in Table 5. The same figure presents the notation related to unit costs of resources and emissions and the prices of products (Table 6).

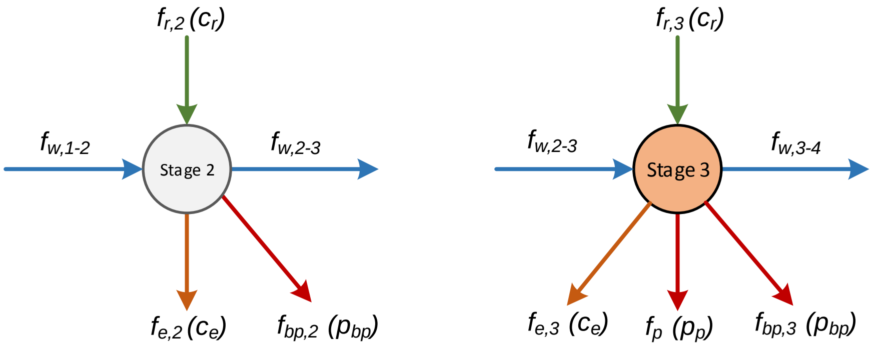

Figure 7 Notation used to represent flows, unit costs and prices (stage 2 is indicative of the water supply stages, while stage 3 corresponds to the water use stage)

Table 5 Flows of different material types in the meso-level water use system

Symbol	Description
$f_{w,i-j}$	Flow of water from stage *i* to stage *j*
$f_{r,i}$	Inflow of resource *r* to stage *i*, from the background system
$f_{e,i}$	Outflow of emission *e* from stage *i* to the environment
f_p	Production of product *p* from the water use stage (stage 3)
$f_{bp,i}$	Production of by-product *bp* from stage *i*

Table 6 Unit cost and unit process of materials in the meso-level water use system

Symbol	Description
c_r	Unit cost of the resource *r*
c_e	Unit cost of the emission *e*
p_p	Unit price of the product *p*
p_{bp}	Unit price of the by-product *bp*

In a typical LCA methodology, the inventory of flows must be related to the functional unit defined in the goal and scope definition. However, it is preferable to express the flows on an annual basis (e.g. m^3 of water abstracted per year, tonnes of product produced in one year…), even if the functional unit is one unit of product or m^3 of water used. This practice makes the calculation of annual costs and incomes easier during the value assessment phase. The environmental impacts per functional unit should be calculated by dividing with the corresponding flow.

In order to develop the inventory, a model of the system is usually constructed using data on inputs and outputs of each process. With respect to data collection, the following guidelines apply:

- For each unit process, an appropriate reference flow is determined (e.g. 1 m^3 of water or 1 MJ of energy).
- The input and output flows of the unit process are calculated in relation to this reference flow through scaling factors.
- SI units (or SI-derived units) are used wherever possible in collecting data for all flows.

2.3.2 Impact assessment

The **life cycle impact assessment** is aimed at evaluating the significance of potential environmental impacts based on the inventory of flows. This stage consists of the following steps:

- Selection of relevant impact categories;
- Classification and characterization, where the inventory flows are assigned to specific impact categories and are characterized into common equivalence units; and
- Impact calculation, where the characterized inventory flows are used to provide an overall environmental impact per category.

2.3.2.1 Environmental impact categories

There is a wide spectrum of indicators that could measure the environmental performance of the water use system. The selection of the most appropriate one is directly related to the information needed in order to make concrete proposals for specific policies.

Table 7 Midpoint impact categories

No	Impact Category	Unit of measure
1	Climate change	$tCO_{2,eq}$
2	Stratospheric ozone depletion	$kgCFC\text{-}11_{eq}$
3	Eutrophication	$kgPO_{4,eq}$ or $kgNO_{x,eq}$
4	Acidification	$kgSO_{2,eq}$
5	Human toxicity	$kg1,4DCB_{eq}$ or CTU_h
6	Ecotoxicity 6.a Aquatic 6.b Terrestrial	$kg1,4DCB_{eq}$ or CTU_e
7	Respiratory inorganics	$kgPM_{10,eq}$
8	Ionizing radiation	kBq $U\text{-}235_{air,eq}$
9	Photochemical ozone formation	$kgC_2H_{4,eq}$
10	Resource depletion 10.a Minerals 10.b Fossil fuels 10.c Freshwater	 $kgSb_{eq}$ or $kgFe_{eq}$ MJ or TOE m^3
11	Land use	ha

The assessment of the environmental performance of the EcoWater meso-level water use system follows a life-cycle oriented approach using the **midpoint impact categories** of Table 7, which make it possible to characterize different environmental problems, such as climate change, ozone depletion, photochemical ozone formation, acidification, eutrophication and resource depletion (Guinée, et al., 2001).

2.3.2.2 Classification and characterization

The purpose of **classification** is to organize and possibly combine the life cycle inventory flows into impact categories. The results of the inventory, expressed as elementary flows, are assigned to impact categories according to the ability of the resource/emission to contribute to different environmental problems.

Characterization concerns the quantification of the extent to which each resource/emission contributes to different environmental impact categories. This step is accomplished using standard **characterization factors**.

The complete list of the environmental impact categories relevant to EcoWater Case Studies is presented in Table 10 (Annex II). In addition to a description and the unit of measurement, this table provides all the relevant resources and/or emissions to be included in the calculation of the environmental performance and the values of the corresponding characterization factors.

2.3.2.3 Environmental impacts from the foreground system

The **environmental impact** for impact category *c* is expressed as a score (ES_C) in a unit common to all contributions within the category. The impacts from the foreground processes are calculated using the flows from the inventory analysis and the characterization factors, as follows:

$$(ES_c)_{fore} = \sum_r cf_{r,c} \times f_r + \sum_e cf_{e,c} \times f_e \qquad (1)$$

where:

$cf_{r,c}$ characterization factor of resource *r* for the impact category *c* (e.g. of water for freshwater depletion, of natural gas for fossil fuel depletion and of phosphorus for mineral depletion);

$cf_{e,c}$ characterization factor of emission *e* for the impact category *c* (e.g. carbon dioxide for climate change, phosphorus for eutrophication and sulphur dioxide for acidification);

f_r elementary flow of resource *r*; and

f_e elementary flow of emission *e*.

The **elementary flows** of resources and emissions are the sum of inventory flows over the stages of the system:

$$f_r = \sum_{i=1}^{4} f_{r,i} \quad \text{and} \quad f_e = \sum_{i=1}^{4} f_{e,i} \qquad (2)$$

2.3.2.4 Environmental impacts from the background system

Background processes are the processes supplying supplementary resources to the foreground system. They are not known in detail and cannot be treated using equation (1). The environmental impacts from these processes are evaluated based on **background or secondary data** taken from **LCA databases**, such as the ELCD database (http://lca.jrc.ec.europa.eu/lcainfohub/datasetArea.vm). The background data, is considered to be generic, normally represented for a mix or a set of mixes of different processes.

Analysing the data provided by the LCA databases, environmental impact factors ($ef_{r,c}$), representing the environmental impacts from the production and/or transportation of one unit of a resource r to each impact category c can be calculated. The contribution of background processes to the environmental impacts of category c is then calculated using these factors, as:

$$(ES_c)_{back} = \sum_r ef_{r,c} \times f_r \tag{3}$$

Background impacts are added to the foreground ones to calculate the system-wide environmental impacts.

$$ES_c = (ES_c)_{fore} + (ES_c)_{back} \tag{4}$$

All the relevant to EcoWater Case Studies background processes are listed in Table 11 of Annex III, while Table 12 presents the environmental impact factors of background processes that are available in free databases.

2.3.2.5 Environmental impact indicators

Environmental impact indicators (EI) are calculated by expressing the environmental impacts per unit of a product or resource (functional unit). Different environmental indicators for each impact category can be calculated, depending on the choice of functional unit (product or water used). Environmental indicators can also be referred to the whole study area or disaggregated on the different clusters.

Type I indicators

Indicators of this type are expressed **per unit of product or service** and are calculated by dividing the environmental score (ES_c, calculated from Equation 4) by the flow of product (f_p from life cycle inventory):

$$(EI_c)_I = \frac{ES_c}{f_p} \tag{5}$$

For example, the climate change environmental indicator of type I $(EI_{c\lim})_I$ in different sectors is defined as in Table 8.

Table 8: Definition of type I impact indicator in different water use sectors.

Sector	Functional Unit	Type I impact indicator
Agricultural	1 tonne of maize	$\frac{\text{tonnes of CO}_{2,eq}\text{ emissions in the water system for maize production}}{\text{tonnes of maize production}}$
Industrial	1 tonne of milk	$\frac{\text{tonnes of CO}_{2,eq}\text{ emissions in the water system for milk production}}{\text{tonnes of milk production}}$
Urban	1 satisfied consumer for a time period	$\frac{\text{tonnes of CO}_{2,eq}\text{ emissions in the water system for supplying water for a certain period}}{\text{number of satisfied consumers during this period}}$

Type I indicators represent the environmental footprint of the product/service. For example, the indicator defined in the first row of Table 8 is the carbon footprint of maize expressed in $tCO_{2,eq}$/tMaize.

Type II indicators

Indicators of this type are expressed **per unit of water used** and are calculated by dividing the environmental score (ES_c, calculated from Equation 4) by the inflow of water in the use stage ($f_{w,2-3}$, from life cycle inventory):

$$(EI_c)_{II} = \frac{ES_c}{f_{w,2-3}} \tag{6}$$

The climate change environmental indicator of type II, for the sectors in Table 8 are now calculated as in Table 9.

Table 9 Definition of type II impact indicator in different water use sectors

Sector	Functional Unit	Type II impact indicator
Agricultural	1 tonne of maize	$\frac{\text{tonnes of CO}_{2,eq}\text{ emissions in the water system for maize production}}{\text{m}^3\text{ of water used for maize production}}$
Industrial	1 tonne of milk	$\frac{\text{tonnes of CO}_{2,eq}\text{ emissions in the water system for milk production}}{\text{m}^3\text{ of water used for milk production}}$
Urban	1 satisfied consumer for a time period	$\frac{\text{tonnes of CO}_{2,eq}\text{ emissions in the water system for supplying water for a certain period}}{\text{m}^3\text{ of water used by consumers during this period}}$

Type II indicators represent the environmental footprint of water used. For example, the indicator defined in the first row of Table 9 is the carbon footprint of water used for the production of maize in $tCO_{2,eq}/m^3$ water.

2.3.2.6 Cluster and area indicators

The environmental indicators, as defined above, can be calculated for the whole system area as well as for each cluster in the study area. Equations (1) to (6) provide the cluster indicators, when the flows f_r , f_e , f_p and f_w correspond to the product or service output of the specific cluster.

When a process is common to more than one cluster (e.g. abstraction of water to be used for many products) an appropriate **allocation** method is required to partition the flows and outputs of the process to the appropriate clusters. The allocation should be based on the amount of water used in the productive processes of each cluster.

Area indicators, for a specific product or service, can be calculated by the same equations, when the flows f_r , f_e , f_p and f_w correspond to the total production of the area. The area indicators can be calculated as the mean value of the cluster indicators:

$$\left(EI_c\right)_{I,area} = \frac{\sum\limits_{cluster} f_{p,cluster} \cdot \left(EI_c\right)_{I,cluster}}{\sum\limits_{cluster} f_{p,cluster}} = \frac{\sum\limits_{cluster} ES_{c,cluster}}{\sum\limits_{cluster} f_{p,cluster}} \tag{7}$$

$$\left(EI_c\right)_{II,area} = \frac{\sum\limits_{cluster} f_{w,cluster} \cdot \left(EI_c\right)_{II,cluster}}{\sum\limits_{cluster} f_{w,2-3,cluster}} = \frac{\sum\limits_{cluster} ES_{c,cluster}}{\sum\limits_{cluster} f_{w,2-3,cluster}} \tag{8}$$

2.4 Value assessment

The most relevant economic performance indicator in the meso-level water use system that includes both the water supply and the water use chains is the **Total Value Added** (TVA) to the product due to water use, expressed in monetary units per period, in general per year (Euros/year). It is estimated as:

$$TVA = EVU + VP_{BP} - TFC_{WS} - TFC_{WW} - FC \tag{9}$$

where:

EVU	total economic value from water use;
VP_{BP}	income generated from any by-products of the system;
TFC_{WS}	total financial cost related to water supply provision for rendering the water suitable for the specific use purpose;
TFC_{WW}	total financial cost related to wastewater treatment; and
FC	annual equivalent future cash flow generated from the introduction of new technologies in the system.

The **Economic Value from Water Use** (EVU) refers to the total benefits from direct use of water. The approach followed for estimating EVU depends on whether water is used as a resource in a production process (e.g. water use in industrial and agricultural sectors), or delivers a service to the customers (e.g. water use in urban sector).

In the first case, *EVU* is estimated using the **residual value approach**:

$$EVU = TVP - EXP_{NW} \tag{10}$$

where

$$TVP = \sum_p f_p \times p_p \tag{11}$$

is the **Total Value of Products**, and

$$EXP_{NW} = \sum_r f_{r,3} \times c_r + \sum_e f_{e,3} \times c_e \tag{12}$$

are the **Non-Water Expenses** representing the expenses for all the non-water inputs as well as the costs related to emissions in the water use stage (stage 3).

The above approach cannot be applied in an urban water supply system, because the product is actually the service provided to households. Instead, the estimation of the economic value from water use is based on the customers' willingness to pay for the water services. Based on the assumption that the level of water services provided will not change as a result of technology implementation (i.e. the application of a technology or management practice will not result in supply interruptions or render the quality of water unsuitable for the specific purpose) and that the total utility (the overall satisfaction of wants and needs) does not change between scenarios, the economic value from water use can be estimated by:

$$EVU = EVU^{bl} = WTP \times f_{w,2-3}^{bl} \tag{13}$$

where:

WTP	consumers' willingness to pay for the services provided (defined as the maximum amount a consumer would be willing to pay in order to receive a reliable and adequate water supply); and
$f_{w,2-3}^{bl}$	total quantity of water supplied to the processes of water use stage in the baseline case, as denoted by the superscript *bl.*

The **Total Financial Cost related to Water Supply** (TFC_{WS}) represents the expenses in the processes of water abstraction and water treatment stages (stages 1 and 2):

$$TFC_{WS} = \left(\sum_r f_{r,1} \times c_r + \sum_e f_{e,1} \times c_e \right) + \left(\sum_r f_{r,2} \times c_r + \sum_e f_{e,2} \times c_e \right) \tag{14}$$

and the **Total Financial Cost related to Wastewater** Treatment (TFC_{WW}) represents the expenses in the processes of wastewater treatment stage (stage 4):

$$TFC_{WW} = \sum_r f_{r,4} \times c_r + \sum_e f_{e,4} \times c_e \tag{15}$$

2.5 Eco-efficiency quantification

The **Eco-Efficiency Indicators** (*EEI*) of the meso-level water use systems are defined as ratios of the economic performance (total value added, *TVA*) to the environmental performance of the system (environmental impacts). There are 14 eco-efficiency indicators, one for each environmental impact category *c*.

$$EEI_c = \frac{TVA}{ES_c} \tag{16}$$

An appropriate set of eco-efficiency indicators should be selected for each system, tailored to the goal and scope of the analysis of the specific meso-level water use system. The selected indicators satisfy the following criteria, as presented in Deliverable 1.1 of EcoWater Project (EcoWater, 2012):

- **Relevance to the goal of the analysis**: Permit the evaluation of the effect that alternative technology options and practices have on specific environmental impacts and on the economic value produced in various stages of the water supply and production chains. Alternative technologies are compared on the basis of the selected indicators;
- **Relevance to the meso-level**: Provide a direct measurement of the environmental impacts associated with all the stages of both water supply and production chains, and effectively highlight all potential economic interactions among different actors in both chains;
- **Comprehensiveness and relevance to the analysed Case Studies**: Fully cover all significant environmental issues due to water use in each Case Study. The specificities of each Case Study and the technologies to be assessed in each case have been considered for the selection of indicators;
- **Reliability, simplicity and comparability**: They are verifiable, reproducible and not complex, while at the same time allow for comparisons between alternative scenarios; and
- **Importance for supporting system-wide (meso-level) decisions (policy relevance)**: They are applicable to all similar systems/water use sectors and can be easily understood by decision makers and relevant actors/stakeholders. They can be used to identify areas for improvement by achieving economic benefit and/or mitigating environmental impacts.

Eco-efficiency indicators do not depend on the functional unit considered (there are no type I and type II eco-efficiency indicators). However, they can be calculated on a cluster basis:

$$EEI_{c,cluster} = \frac{TVA_{cluster}}{ES_{c,cluster}} \tag{17}$$

and aggregated on the study area:

$$EEI_{c,area} = \frac{TVA_{area}}{ES_{c,area}} = \frac{\sum_{cluster} TVA_{cluster}}{\sum_{cluster} ES_{c,cluster}} \tag{18}$$

3 Special methodological issues

The section addresses four special methodological issues regarding: a) the handling of "recovered resources" (e.g. energy, phosphorus, etc.), generated due to the implementation of innovative technologies, b) the assessment of environmental impacts from freshwater use, c) the assessment of the environmental impacts from thermal pollution and d) the assessment of the environmental impacts from micropollutants in water effluents.

3.1 Recovered resources

Recovered resources, as a result of applying an innovative technology, will alter the eco-efficiency of the water system and this impact should be included in the analysis. The problem is more important when the recovered resources are exported and used outside of the system boundaries. In a typical life LCA methodology, this problem is handled by an expansion and substitution approach.

According to JRC (2010), when a process of a system provides more than one function, i.e. delivers several goods and/or services, it is defined as multifunctional. Multifunctionality in the analyzed meso-level water use systems occurs due to the introduction of innovative technologies, as e.g. in the following cases:

- Introduction of a hydropower generator, which functions as a pressure reduction valve, in the water distribution process. The generated electricity can be used on-site, exported to the grid or stored into batteries for future usage.
- Introduction of advanced phosphorus recovery technologies in the processes of the wastewater treatment stage. The recovered phosphorus can be sold for use to another system.

The environmental impacts of these multifunctional processes will be considered as follows:

- In case of on-site use of the generated resource (closed-loop recycling) the consumption of primary and supplementary resources is reduced, affecting the environmental performance of the system; hence their amount will be subtracted from the relevant elementary flow during the environmental impact assessment. The economic performance of the system is affected as well (as the costs related to resources used and the additional technology is considered for the estimation of the TVA).
- In case that the recovered resources (generated electricity or phosphorus) are exported to another system (open-loop recycling) the economic and the environmental performance of the analysed system are affected as follows:
    - The cash flow from the sale of recovered resources will be considered for the estimation of the TVA produced, as a benefit of the relevant actor due to technology uptake.
    - The potential environmental benefits associated with the use of recovered resources (e.g. reduced amount of primary materials and energy sources) will not be considered, as they are ascribed to the system where the use of resources takes place.

3.2 Assessment of environmental impacts from freshwater use

Impacts from the use of freshwater (resource depletion) are far from being standardized in current LCIA practice (Muñoz, et al., 2010) and there is no standardized environmental midpoint indicator for this impact category (JRC, 2011). To date, most studies have neglected this issue or reflected it as a simple indicator expressing the volume of abstracted water by the product system (Muñoz, et al., 2008).

The methodology proposed in Mila i Canals (2009) and suggested by JRC (2011) is recommended. It is based on the Freshwater Ecosystem Impact (FEI) indicator, defined as:

$$FEI = f_{w,0-1} \times WTA \tag{19}$$

where:

$f_{w,0-1}$ flow of freshwater abstracted; and
WTA water withdrawal to availability ratio, defines as:

$$WTA = \frac{WU}{WR} \tag{20}$$

where:

WU total annual freshwater withdrawal in a river basin; and
WR annual freshwater availability in the same basin.

3.3 Assessment of environmental impacts from thermal pollution

Impacts from thermal pollution have not been standardized in current LCIA practice. However, such an impact is common, mainly in the case of an industrial value chain, where river water is abstracted and used for cooling purposed. After its use, the water has relatively low temperature so it is not possible to further use it in the value chain and is thus discharged to the river. The waste heat rejected is considered as thermal pollution, since it affects the temperature of lake or river water and negatively influences the biodiversity.

Additionally, according to literature review on temperature and aquatic ecosystems, thermal discharges can alter population of phytoplankton; accelerate the growth of bacteria and affect the fish populations (U.S. EPA, 2011). LCA studies do not properly address the potential effects caused by thermal pollution due to the lack of available data. Several approaches have been proposed in order to estimate the impact of thermal pollution to aquatic biodiversity, based on the ecological value of water in the considered ecosystem. Ultimate impacts on ecosystem quality are commonly expressed in potentially disappeared fraction (PDF) of species on a given surface or volume during a given time (PDF per square meter per year or PDF per cubic meter per year) (Verones, 2010).

In the EcoWater Case Studies, thermal pollution is an important environmental impact in the case of energy production industry. However, its assessment is based on the absolute value waste heat (in GJ), due to lack of data.

3.4 The assessment of the environmental impacts in urban sector

According to the targets of the EU-WFD, there is a necessity for further reduction of pollutant emissions from wastewater treatment plants (WWTP). The high concentration in organics, nutrients or trace pollutants of waste water flows can only be faced using advanced technologies for tertiary filtration or removal of micropollutants. Furthermore, according to Switzerland’s new Water Protection Ordinance, around 100 out of its more than 700 WWTPs will have to be upgraded to halve the currently discharged micropollutants.

Thus, in order to assess the performance of innovative removal technologies, the impact of micropollutants in human health and the environmental should be quantified and estimated.

However, such an impact and the relevant elementary flows have not been included in the in midpoint environmental impact categories and the respective metrics. In the case of Zurich urban water supply system, a first approximation is made by using an ancillary indicator for micropollutants emissions, measured in kg per year. The value is estimated by using the average concentrations of most typical micropollutants for Switzerland, measured at the outlet of wastewater treatment plants reported by the Swiss Federal Office for the Environment.

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Annex I: Symbols

c_r	Unit cost of the resource *r*
c_e	Unit cost of the emission *e*
$cf_{r,c}$	Characterization factors of the impact category *c* for the resource *r*
$cf_{e,c}$	Characterization factors of the impact category *c* for the emission e
EEI_c	Eco-efficiency indicators for the impact category *c*
EI_c	Midpoint environmental indicator for the impact category *c*
ES_c	Environmental impact score for impact category *c*
$ef_{r,c}$	Environmental impact factor of resource *r* for impact category c
EVU	Total economic value of water use
EXP_{NW}	Expenses for all the non-water inputs
FC	*A*nnual equivalent future cash flow generated from the introduction of new technologies in the system
FEI	Freshwater ecosystem impact
$f_{bp,i}$	Flow of by-product *bp* from stage *i*
$f_{w,i-j}$	Flow of water from stage *i* to stage *j*
f_r	Elementary flow of resource *r*
$f_{r,i}$	Inflow of supplementary resource *r* to stage *i*
f_e	Elementary flow of emission *e*
$f_{e,i}$	Outflow of emission *e* from stage *i*
f_p	Flow of product *p* from water use stage
p_{bp}	Unit price of the by-product *bp*
p_p	Unit price of the product *p*
TFC_{WS}	Total financial cost related to water supply provision for rendering the water suitable for the specific use purpose
TFC_{WW}	Total financial cost related to wastewater treatment
TVA	Total Value Added
TVP	Total Value of the Products
VP_{BP}	Income generated from any by-products of the system
WTA	Water withdrawal to availability ratio
WTP	The consumers’ willingness to pay for the services provided

WR	Annual freshwater availability in a river basin
WU	Total annual freshwater withdrawal in a river basin

Annex II: Midpoint environmental impact categories

Table 10 Environmental impact categories, relevant to EcoWater Case Studies

Climate Change	
Description	Climate change is defined as the impact of human emissions on the radiative forcing (heat radiation absorption) of the atmosphere, which results in the rise of the earth's surface temperature (greenhouse effect).
Indicator	Radiative forcing as Global Warming Potential (GWP): reflects the relative effect of the emissions of greenhouse gases into the air, considering a fixed time period (i.e. 100 years).
Unit of Measure	$tCO_{2,eq}$
Characterization factors of relevant supplementary resources / emissions	Carbon Dioxide (CO_2): 1 t $CO_{2,eq}/tCO_2$ Methane (CH_4): 25 $tCO_{2,eq}/tCH_4$ Nitrous Oxide (N_2O): 298 $tCO_{2,eq}/tN_2O$ Methylene Chloride (CH_2Cl_2): 8.7 $tCO_{2,eq}/tCH_2Cl_2$ Hydrofluorocarbons; e.g. HFC-134a: 1430 $tCO_{2,eq}$/tHFC-134a Perfluorocarbons; e.g. CF_4: 7390 $tCO_{2,eq}/tCF_4$ Sulphur hexafluoride (SF_6): 22800 $tCO_{2,eq}/tSF_6$
Relevant EcoWater Case Studies	All
References	(Guinée, et al., 2001; IPCC, 2007)
Stratospheric Ozone Depletion	
Description	Stratospheric ozone depletion is the thinning of the stratospheric ozone layer due to anthropogenic emissions (i.e. CFCs and Halons) and results in a greater fraction of solar UV-B radiation reaching the earth's surface.
Indicator	Ozone Depletion Potential (ODP): expresses the amount of ozone destroyed by ozone depleting substances, considering steady-state ozone depletion.
Unit of Measure	$kgCFC\text{-}11_{,eq}$
Characterization factors of relevant supplementary resources / emissions	Chlorofluorocarbons: 1 $kgCFC\text{-}11_{,eq}$/ kgCFC-11, CFC-113: 0.90 $kgCFC\text{-}11_{,eq}$/kgCFC-113 Hydrochlorofluorocarbons: 0.026 $kgCFC\text{-}11_{,eq}$/kg HCFC-124 Halons; e.g. Halon-1301: 12 $kgCFC\text{-}11_{,eq}$/kg Halon-1301 Methyl Bromide (CH_3Br): 0.37 $kgCFC\text{-}11_{,eq}/kgCH_3Br$ Tetrachloromethane (CCl_4): 1.2 $kgCFC\text{-}11_{,eq}/kgCCl_4$
Relevant EcoWater Case Studies	All

References	(Guinée, et al., 2001; Goedkoop, et al., 2008; EPA, 2006)	
Eutrophication		
Description	Eutrophication covers all potential impacts of excessively high environmental levels of macronutrients, the most important of which are nitrogen (N) and phosphorus (P). Nutrient enrichment may cause an undesirable shift in species composition and elevated biomass production in both aquatic and terrestrial ecosystems. In addition, high nutrient concentrations may also render surface waters unacceptable as a source of drinking water.	
Indicator	Eutrophication Potential (EP): measures the fraction of nutrients, which cause over-fertilization of water.	
Unit of Measure	$kgPO_{4,eq}$ or $kgNO_{x,eq}$	
Characterization factors of relevant supplementary resources / emissions	Ammonia (NH_3):	0.35 $kgPO_4^{3-}{}_{,eq}/kgNH_3$
	Ammonium (NH_4^+):	0.33 $kgPO_4^{3-}{}_{,eq}/kgNH_4^+$
	Nitrates (NO_3^-):	0.1 $kgPO_4^{3-}{}_{,eq}/kgNO_3^-$
	Nitric Acid (HNO_3):	0.1 $kgPO_4^{3-}{}_{,eq}/kgHNO_3$
	Nitrogen Total (N):	0.42 $kgPO_4^{3-}{}_{,eq}/kgN$
	Nitrogen Monoxide (NO):	0.2 $kgPO_4^{3-}{}_{,eq}/kgNO$
	Nitrogen Dioxide (NO_2):	0.13 $kgPO_4^{3-}{}_{,eq}/kgNO_2$
	Nitrogen Oxides (NO_x):	0.13 $kgPO_4^{3-}{}_{,eq}/kgNO_x$
	Nitrous Oxide (N_2O):	0.27 $kgPO_4^{3-}{}_{,eq}/kgN_2O$
	Phosphates (PO_4^{3-}):	1 $kgPO_4^{3-}{}_{,eq}/kgPO_4^{3-}{}_{,eq}$
	Phosphoric Acid (H_3PO_4):	0.97 $kgPO_4^{3-}{}_{,eq}/kgH_3PO_4$
	Total Phosphorus (P):	3.06 $kgPO_4^{3-}{}_{,eq}/kgP$
	Phosphorus Oxide (P_2O_5):	1.34 $kgPO_4^{3-}{}_{,eq}/kgP_2O_5$
	Chemical Oxygen Demand (COD):	0.022 $kgPO_4^{3-}{}_{,eq}/kgCOD$
Relevant EcoWater Case Studies	All	
References	(Guinée, et al., 2001)	
Acidification		
Description	Acidification refers to the processes that increase the acidity of water and soil systems through hydrogen ion concentration and it is caused by the acidifying effects of anthropogenic emissions (i.e. NO_x, SO_2).	
Indicator	Acidification Potential (AP): describes the impacts of emissions of acidifying substances on natural ecosystems. The time span is eternity and the geographical scale varies between local and continental.	
Unit of Measure	$kgSO_{2,eq}$	

Characterization factors of relevant supplementary resources / emissions	Ammonia (NH_3): 1.88 $kgSO_{2,eq}/kgNH_3$ Hydrogen Chloride (HCl): 0.88 $kgSO_{2,eq}/kgHCl$ Hydrogen Fluoride (HF): 1.60 $kgSO_{2,eq}/kgHF$ Hydrogen Sulfide (H_2S): 1.88 $kgSO_{2,eq}/kgH_2S$ Nitrogen Oxides (as NO_2): 0.70 $kgSO_{2,eq}/kgNO_2$ Phosphoric Acid (H_3PO_4): 0.98 $kgSO_{2,eq}/kgH_3PO_4$ Sulphur Dioxide (SO_2): 1 $kgSO_{2,eq}/kgSO_2$ Sulphuric Acid (H_2SO_4): 0.65 $kgSO_{2,eq}/kgH_2SO_4$
Relevant EcoWater Case Studies	All
References	(Guinée, et al., 2001; Goedkoop, et al., 2008)
Human Toxicity	
Description	Human toxicity refers to the impacts of toxic substances present in the environment on human health.
Indicator	Human Toxicity Potential (HTP): expresses the degree to which a chemical substance elicits an adverse effect on the biological system of human exposed to it over a designated time period (e.g. 100 years).
Unit of Measure	$kg1,4DCB_{eq}$ or CTU_h
Characterization factors of relevant supplementary resources / emissions	More than 450 substances, including polycyclic aromatic HCs (PAHs), halogenated aromatic and non-aromatic HCs, alkanes, alkenes. Indicative characterization factors are the following: **Textile Industry:** • Chromium (VI) (to fresh water): 2.1 $kg1.4DCB_{,eq}/kg$ Cr **Automotive Industry:** • Nickel (to fresh water): 331.08 $kg1.4DCB_{,eq}/kg$ Ni • Zinc (to fresh water): 0.584 $kg1.4DCB_{,eq}/kg$ Zn **Urban Water Systems** • Cadmium (to fresh water): 22.89 $kg1.4DCB_{,eq}/kg$ Cd
Relevant EcoWater Case Studies	CS#5, CS#8
References	(Guinée, et al., 2001)
Ecotoxicity - Aquatic	
Description	Freshwater aquatic ecotoxicity refers to the impacts of toxic substances on freshwater aquatic ecosystems.
Indicator	Freshwater aquatic ecotoxicity potential (FAETP): describes fate, exposure and effects of toxic substances to air, water, and soil. The time horizon is infinite and the indicator applies at global,

	continental, regional, local scale.
Unit of Measure	kg1,4DCB$_{eq}$ or CTU$_{e}$
Characterization factors of relevant supplementary resources / emissions	More than 450 substances, including polycyclic aromatic HCs (PAHs), halogenated aromatic and non-aromatic HCs, alkanes, alkenes. Indicative characterization factors are the following: **Textile Industry:** - Chromium (VI) (to freshwater): 27.65 kg1.4DCB$_{,eq}$/kgCr **Automotive Industry:** - Nickel (to freshwater): 3237 kg1.4DCB$_{,eq}$/kg Ni - Zinc (to freshwater): 91.71 kg1.4DCB$_{,eq}$/kg Zn **Urban Water Systems** - Cadmium (to freshwater): 1523 kg1.4DCB$_{,eq}$/kg Cd
Relevant EcoWater Case Studies	CS#3, CS#4, CS#5, CS#7, CS#8
References	(Guinée, et al., 2001)
Ecotoxicity - Terrestrial	
Description	Terrestrial ecotoxicity refers to toxic substances on terrestrial ecosystems.
Indicator	Terrestrial Ecotoxicity Potential (TETP): describes fate, exposure and effects of toxic substances to air, water, and soil. The time horizon is infinite and the indicator applies at global, continental, regional, local scale.
Unit of Measure	kg1,4DCB$_{eq}$ or CTU$_{e}$
Characterization factors of relevant supplementary resources / emissions	More than 450 substances, including polycyclic aromatic HCs (PAHs), halogenated aromatic and non-aromatic HCs, alkanes, alkenes. Indicative characterization factors are the following: **Textile Industry:** - Chromium (VI) (to agri. soil): 6300 kg1.4DCB$_{,eq}$/kg Cr **Automotive Industry:** - Nickel (to agri. soil): 238.5 kg1.4DCB$_{,eq}$/kg Ni - Zinc (to agri. soil): 24.5 kg1.4DCB$_{,eq}$/kg Zn **Urban Water Systems** - Cadmium (to agri. soil): 166.8 kg1.4DCB$_{,eq}$/kg Cd
Relevant EcoWater Case Studies	CS#3, CS#4, CS#5, CS#7, CS#8
References	(Guinée, et al., 2001)

Respiratory Inorganics	
Description	Respiratory effects resulting from particulate matter (PM) due to emissions of primary or secondary particulates. Emissions of SO_2 and NO_x that create sulphate and nitrate aerosols are included in secondary emissions, resulting from combustion.
Indicator	Particulate Matter Potential (PMP): accounts for environmental fate, exposure and dose-response of a pollutant (Midpoint).
Unit of Measure	$kgPM_{2.5,eq}$
Characterization factors of relevant supplementary resources / emissions	PM_{10} $PM_{2.5}$ $PM_{0.1}$
Relevant EcoWater Case Studies	
References	(Guinée, et al., 2001)

Ionizing Radiation	
Description	Ionizing radiation covers the impacts arising from emissions of radioactive substances to air, water and soil, as well as direct exposure to radiation (α-, β-, γ-rays, neutrons), which is harmful to both human beings and animals.
Indicator	Ionizing Radiation Potential (IRP): measures the effects caused by the adsorbed radiation, taking into account the emissions and the calculation of their radiation behaviour and burden.
Unit of Measure	kBq $U\text{-}235_{air,eq}$
Characterization factors of relevant supplementary resources / emissions	Indicative characterization factors are the following: C-14 (to air): 0.94 kBq $U\text{-}235_{air,eq}$/kBq C-14 Pu-alpha (to air): 4.1 kBq $U\text{-}235_{air,eq}$/kBq Pu-alpha Ra-226 (to air): 0.045 kBq $U\text{-}235_{air,eq}$/kBq Ra-226 U-235 (to air): 1 kBq $U\text{-}235_{air,eq}$/kBq $U\text{-}235_{air,eq}$ Co-60 (to rivers): 2.2 kBq $U\text{-}235_{air,eq}$/kBq Co-60 Cs-137 (to rivers): 8.2 kBq $U\text{-}235_{air,eq}$/kBq Cs-137 Sb-125 (to ocean): 0.0071 kBq $U\text{-}235_{air,eq}$/kBq Sb-125
Relevant EcoWater Case Studies	
References	(Guinée, et al., 2001; Frischknecht, et al., 2000)

Photochemical Ozone Formation	
Description	Photochemical ozone formation refers to the formation of reactive chemical compounds such as ozone by the action of sunlight on certain primary air pollutants (VOCs, CO, NO_x).
Indicator	Photochemical Ozone Creation Potential (POCP): measures the impacts from emissions of substances to air.
Unit of Measure	$kgC_2H_{4,eq}$
Characterization factors of relevant supplementary resources / emissions	Indicative characterization factors are the following: 1-Butene: 1.08 $kgC_2H_{4,eq}/kgC_4H_8$ Carbon monoxide: 0.027 $kgC_2H_{4,eq}/kgCO$ Isobutene: 0.307 $kgC_2H_{4,eq}/kgC_4H_8$ Methane: 0.006 $kgC_2H_{4,eq}/kgCH_4$ Nitrous oxides: 0.028 $kgC_2H_{4,eq}/kgNO_x$ Propylene: 1.12 $kgC_2H_{4,eq}/kgC_3H_6$ Sulphur dioxide: 0.048 $kgC_2H_{4,eq}/kgSO_2$ Tetrachloroethylene: 0.029 $kgC_2H_{4,eq}/kgC_2Cl_4$
Relevant EcoWater Case Studies	
References	(Guinée, et al., 2001)

Resource Depletion - Minerals	
Description	Resource depletion refers to the decreasing availability of resources (minerals), as a result of their consumption beyond the rate of renewal/replacement.
Indicator	Resource Depletion Potential (RDP): measures the consumption of non-renewable resources, i.e. minerals.
Unit of Measure	$kgSb_{eq}$ or $kgFe_{eq}$
Characterization factors of relevant supplementary resources / emissions	All elements. Indicative characterization factors are the following: Aluminium (Al): 1×10^{-8} kg $Sb,_{eq}$/ kg Al Antimony (Sb): 1.00 kg $Sb,_{eq}$/ kg Sb Bromine (Br): 0.00667 kg $Sb,_{eq}$/ kg Br Cadmium (Cd): 0.33 kg $Sb,_{eq}$/ kg Cd Chlorine (Cl): 4.86×10^{-8} kg $Sb,_{eq}$/ kg Cl Iron (Fe): 8.43×10^{-8} kg $Sb,_{eq}$/ kg Fe Lead (Pb): 0.0135 kg $Sb,_{eq}$/ kg Pb Magnesium (Mg): 3.73×10^{-9} kg $Sb,_{eq}$/ kg Mg Manganese (Mn): 1.38×10^{-5} kg $Sb,_{eq}$/ kg Mn Nickel (Ni): 0.000108 kg $Sb,_{eq}$/ kg Ni Phosphorus (P): 8.44×10^{-5} kg $Sb,_{eq}$/ kg P Sodium (Na): 8.42×10^{-11} kg $Sb,_{eq}$/ kg Na

	Sulfur (S): 0.000358 kg $Sb_{,eq}$/ kg S Zinc (Zn): 0.000992 kg $Sb_{,eq}$/ kg Zn
Relevant EcoWater Case Studies	CS#8
References	(Guinée, et al., 2001)
Resource Depletion – Fossil Fuels	
Description	Resource depletion refers to the decreasing availability of resources (fossil fuels), as a result of their consumption beyond the rate of renewal/replacement.
Indicator	Resource Depletion Potential (RDP): measures the consumption of non-renewable resources, i.e. fossil fuels.
Unit of Measure	MJ or TOE
Characterization factors of relevant supplementary resources / emissions	All elements. Indicatively, the calorific values of consumed fuels are the following: Coal hard: 28.9 MJ/kg Coal soft, lignite: 8.4 MJ/kg Natural gas: 38.00 MJ/m^3 Crude oil: 45.6 MJ/kg
Relevant EcoWater Case Studies	All
References	(Guinée, et al., 2001)
Resource Depletion – Freshwater	
Description	Freshwater depletion refers to the decreasing availability of freshwater resources, due to their abstraction. Measures the impacts on freshwater ecosystems due to freshwater abstraction.
Indicator	Resource Depletion Potential (RDP): measures the impacts on freshwater ecosystems due to water resource depletion.
Unit of Measure	m^3 of “ecosystem-equivalent” water
Characterization factors of relevant supplementary resources / emissions	Fresh water abstracted. Withdrawal-to-availability ratio of the river basin (WTA).
Relevant EcoWater Case Studies	All
References	(Guinée, et al., 2001)

Annex III: Background processes

Table 11 Background processes relevant to EcoWater Case Studies

Case Study	Background Processes	Databases		
		ELCD	NREL U.S. LCI	Ecoinvent
All	Electricity Production	x	x	x
#1	Diesel Production	x		x
#1, 2	(N) Fertilizer Production		x	x
#1, 2	(P) Fertilizer Production		x	x
#3	Heat Production		x	x
#3, 4	Aluminium Sulphate (Al_2SO_4 / $Al_2(SO_4)_3$) Production			x
#3, 7	Transport	x	x	x
#3, 8	Iron (III) Chloride ($FeCl_3$) Production			x
#3, 4, 7, 8	Chlorine (Cl_2) Production	x	x	x
#4, 5, 6, 7	Natural Gas Production			
#4	Aluminium Polychlorosulphate Production			
#4	Chlorine Dioxide (ClO_2) Production			x
#4	Sodium Hypochlorite (NaClO) Production			x
#4	Sodium Chlorite ($NaClO_2$) Production			
#4	Ozone (O_3) Production			x
#4	Citric Acid ($C_6H_8O_7$) 50% Production			
#4	Nitric Acid (HNO_3) Production			x
#4	Ferric Chlorosulphate ($FeCl(SO_4)$) Production			
#4	Flocculants Polyacrylamide-based (Zetag, FlocStar, Praestol 50003) Production			
#4	Polyaluminium Chloride (PAX-18) Production			
#4, 7	Sodium Hydroxide (NaOH) Production	x		x
#5	Wool Production			x
#7	Raw Milk Production			x

Case Study	Background Processes	Databases		
		ELCD	NREL U.S. LCI	Ecoinvent
#7	Sodium Chloride (NaCl) Production	x	x	x
#7	Potassium Hydroxide (KOH) Production			x
#7	Phosphoric Acid (H_3PO_4) Production			x
#7	Nitric Acid (HNO_3) Production			x
#7	Hydrochloric Acid (HCl) Production	x	x	x
#7	Hydroxyacetic Acid Production			
#7	Citric Acid Production			
#7	Paracetic Acid Production			
#7	Quaternary Ammonium Production			
#7	Protease			
#7	Lipase			
#7	Amylase		x	
#8	Heat from District Heating Production			
#8	Alkaline phosphates / Hydroxides (Ridoline) Production			
#8	$Zn_3(PO_4)_2$ / $Ni_3(PO_4)_2$ (Granodine) Production			
#8	Anionic Polyacrylamide (Sedifloc 740A) Production			
#8	Lime ($Ca(OH)_2$) Production			x
#8	Activated Carbon Production			x
#8	Phosphorus in chemicals			
#8	Nickel in chemicals			
#8	Zinc in chemicals			
#8	Dolomite Production			x
#8	Sand Production	x		x

Table 12 Environmental impact factors for background processes relevant to EcoWater Case Studies

Background Processes	**Environmental Impact Categories**								
	Climate Change	**Ozone Depletion**	**Eutrophication**	**Acidification**	**Human Toxicity**	**Freshwater Aquatic Ecotoxicity**	**Terrestrial Ecotoxicity**	**Photochemical Oxidation**	**Abiotic Depletion**
	kg $CO_{2, eq}$	**kg CFC-11$_{, eq}$**	**kg $PO_{4, eq}$**	**kg $SO_{2, eq}$**	**kg 1,4-DB$_{, eq}$**	**kg 1,4-DB$_{, eq}$**	**kg 1,4-DB$_{, eq}$**	**kg $C_2H_{4, eq}$**	**kg Sb,eq**
Electricity Production BG mix (per kWh)	0.906528	2.41E-07	0.000408	0.033003	0.09155	0.003009	0.002627	0.001282	0.005431
Electricity Production DK mix (per kWh)	0.760926	3.52E-10	0.00015	0,001454	0.017213	0.000559	0.000377	5.53E-05	0.00377
Electricity Production SW mix (per kWh)	0.111676	1.77E-07	2.04E-05	0.000203	0.006125	0.000388	5.97E-05	7.96E-06	0.000305
Electricity Production PT mix (per kWh)	0.770439	4.73E-09	0.000296	0.006062	0.066476	0.003106	0.001536	0.000254	0.00414
Electricity Production IT mix (per kWh)	0.70787	N/A	0.00017	0.00407	0.09159	0.00184	0.00090	0.00018	0.00424
Diesel Production (per kg)	0.38199	N/A	0.00018	0.00257	0.03782	0.00296	0.00101	0.00023	0.0247
Degreasing Chemicals (per kg)	0.9311	N/A	0.0068	0.0216	N/A	N/A	N/A	0.0019	N/A
Phsophating Chemicals	8.9254	N/A	0.0042	0.0166	N/A	N/A	N/A	0.0012	N/A

Background Processes	**Environmental Impact Categories**								
	Climate Change	**Ozone Depletion**	**Eutrophication**	**Acidification**	**Human Toxicity**	**Freshwater Aquatic Ecotoxicity**	**Terrestrial Ecotoxicity**	**Photochemical Oxidation**	**Abiotic Depletion**
	kg $CO_{2, eq}$	**kg CFC-11, eq**	**kg $PO_{4, eq}$**	**kg $SO_{2, eq}$**	**kg 1,4-DB, eq**	**kg 1,4-DB, eq**	**kg 1,4-DB, eq**	**kg $C_2H_{4, eq}$**	**kg Sb,eq**
(per kg)									
Nitrogen Fertilizer Production (per kg)	1.93006	N/A	0.00035	0.02339	0.64951	0.22896	0.00022	0.00100	0.02
Phosphorus Fertilizer Production (per kg)	0.39097	N/A	0.06724	0.02197	0.16316	0.08853	0.00063	0.00093	0.00302
Chlorine Production	1.13614	0	0.000365	0.00859	0.009089	0.0003637	0.0191919	0.0003419	0.00602
Sodium Hydroxide Production	1.3924	0	0.000408	0.007344	0.005964	0.000155	0.004908	0.000326	0.00707
Sodium Chloride Production	0.16488	0	5.5E-05	0.001127	0.001002	2.66E-05	0.000291	4.43E-05	0.000919
Sand	1.48E-05	3.83E-10	1.32E-08	1.14E-05	1.90E-04	2.17E-01	2.41E-06	5.16E-07	1.16E-12