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Environmental indicators and methods with focus on water related impacts

Master of Science Thesis in the Master's Programme Environmental Measurements and Assessments

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Department of Civil and Environmental Engineering
Water Environment Technology
CHALMERS UNIVERSITY OF TECHNOLOGY
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Abstract

Nowadays, one of the most important problems that our societies have to face is water scarcity. Increasing population growth and human activities lead to increasing freshwater consumption and scarcity so in recent years, different indicators and methods have been developed for evaluating and assessing the impacts of freshwater consumption and water scarcity.

This study has two aims. The first aim of this project is presenting an inventory and assessment of existing and proposed environmental indicators for European Union countries, with a focus on water use and water-related indicators. The second part aims at providing an overview of four methods of evaluating the impacts of freshwater use in Life Cycle Assessment (LCA), comparing them based on the selected criteria and sub-criteria, and finally proposing the best method.

Milà i Canals et al. method (2009), Pfister et al. method (2009), Ecological Scarcity method (2006), and Water footprint method (2011) are the four selected methods which are evaluated by this study based on some criteria such as environmental issues addressed, type of water, type of water (blue, green and gray), relevance, and comprehensiveness.

According to the final results of this study, Water footprint method (2011) has the highest grade, and it is recommended as the best method by this report. This method can be regarded as a comprehensive method for evaluating the water consumption in LCA, due to several criteria which are considered by this study such as a broad range of environmental (water) issues, three types of water (blue, green and gray), two types of water use (consumptive and degradative), provides a complete and suitable background knowledge, and an easy to understand approach for stakeholders.

Keyword: Environmental indicators, Water indicators, Freshwater use, Method review.

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Göteborg, Sweden, November 2013

Melina Ettehad

Nomenclature

AP- Area of protection

CEC- Cause and effect chain

COP- Comprehensiveness

DOC- Documentation

EEA- European Environment Agency

EI- Environmental issues

EMInInn- Environmental Macro Indicators of Innovation

EU- European Union

Eurostat- Statistical Office of the European Communities

LCA- Life Cycle Assessment

LCIA- Life Cycle Impact Assessment

MEA- Meaning

SD- Spatial differentiation

TW- Type of water

TWU- Type of water use

1 Introduction

Water is a precious and vital resource for human well-being, all ecosystems and different economic activities. In recent years, increasing population growth and human activities lead to increasing freshwater consumption and scarcity. The population of the world is growing by around 80 million people each year, and the demand of freshwater is increasing by 64 billion cubic meters a year because of this population growth, the production of biofuels, the changes toward a more water demanding lifestyle, and the energy demand (Kounina et al., 2013, WWDR, 2012).

Nowadays, one of the most important problems that our societies have to face is water scarcity. The quantity of freshwater resources is enough for seven billion people but the distribution does not fit the demand, and in most of the cases is polluted, wasted, and unsustainably managed (Decade, 2013).

Since access to good quantity and quality of freshwater is one of the most important aspects for the development of the societies, in recent years different indicators and methods have been developed for evaluating and assessing the water scarcity and the impacts of freshwater consumption.

1.1. Background

Innovation and technological changes are necessary for economic and society growth but the impacts of them should be managed in a sustainable approach so for reaching this goal different changes should be recognized, monitored and controlled.

Indicators are a tool for monitoring and controlling the complicated system that we work with it. Indicators help us understand the problems and improve the system by increasing our information about each system; as a matter of fact they can help decision makers in problem solving process by providing required information (Meadows, 1998).

Donella Meadows (1998) has defined indicator in this way: "indicators arise from values (we measure what we care about) and they create value (we care about what we measure)" (Meadows, 1998).

Also according to the final report of PALMER development group (2004) indicator is described in this way: "Indicators are essentially pieces of information that reveal conditions, and over time, trends. Indicators can be used to make policy and planning decisions, to identify whether policy goals and targets are being met, and sometimes to predict change. Indicators can also be used to compare conditions of different locales or progress towards policy targets" (PALMER, 2004).

There are many different indicators and methods (a set of indicators) with different trends, goals, targets, limitations, generators, and time so choosing the best indicator and method is the first and the most important steps of the monitoring and problem solving process.

1.2. Aims and objectives

This study includes two main parts. The first part of this project is an inventory and assessment of existing and proposed environmental indicators for EU countries, with a focus on water use and water-related indicators. The second part aims at providing an overview of four methods for evaluating the impacts of freshwater use in LCA, and comparing them based on the selected criteria and sub-criteria.

The objectives of the project include the following:

•Present a literature review covering research related to environmental indicators for EU countries with the focus on the water issues

•Analyze and compare the selected methods based on some criteria and sub-criteria

•Select and propose the best method for monitoring the impacts of freshwater consumption in LCA

1.3. Scope

This project provides an inventory of environmental indicators to monitor the innovation impacts in member states of EU, in EU as a whole, and on the global level.

The focus of the study is on water use and water-related environmental indicators. However, the project also includes an overview of four international methods for evaluating the impacts of freshwater use in LCA.

2 Terminology

In-stream (non—withdrawal) water use: water use taking place within a channel of stream such as navigation, hydroelectric power generation, recreation, and fish farming (USGS, 2013a).

Off-stream (withdrawal) water use: water diverted or withdrawn from a surface or groundwater or —water source for industry, public water supply, irrigation, thermoelectric power generation, livestock, and other uses (USGS, 2013b).

Degradative water use: Pfister (2010) described degradative use in this way: “Degradative use is water released into the same watershed it was withdrawn from, with changed quality” (Pfister, 2010).

Consumptive water use: product integration, evaporation, transfers of water to different river basins, and release water to sea (Pfister, 2010).

Blue water footprint (WFP): refers to blue water resources (surface and groundwater) consumption along the product supply chain of a product. ‘Consumption’ refers to water loss from the available surface and ground water body in a specific catchment area (Hoekstra et al., 2011).

Green WFP: refers to green water rainwater resources (soil moisture) consumption (Hoekstra et al., 2011).

Grey WFP: refers to water pollution. It is an indicator for measuring the freshwater pollution degree that can be related to the process step (Hoekstra et al., 2011).

Midpoint impact category (problem-oriented approach): translates different impacts into the environmental themes such as human toxicity, climate change, acidification, etc. (PE, 2013).

Endpoint impact category (the damage-oriented approach): translates different environmental impacts into relevant issues of concern such as natural environment, human health, and natural resources (PE, 2013).

Watershed: the area where all the water that is drains of it or under it goes into the same area. EPA (2012) described it in this way: watershed is: "That area of land, a bounded hydrologic system, within which all living things are inextricably linked by their common water course and where, as humans settled, simple logic demanded that they become part of a community" (EPA, 2012).

DPSIR: an integrated approach and framework for reporting in the sustainable development field. This framework defined a causal chain which starts with “Driving force” (human activities, economic sectors) trough “Pressures” (waste, emissions) to “States” (chemical, physical and biological), “Impacts” (impacts on resources, human health and ecosystem), and finally leading to “Responses” (target setting, prioritization, indicators) (Kristensen, 2004).

3 Materials and Methods

This project have been designed according to DMAIC methodology (the project methodology developed by Six Sigma) which includes Define, Measure, Analyze, Improve and Control steps (see Figure 1).

The information and data of this study have been gathered by using resources like:

- Literature (books, articles, theses, etc.)

- Internet

The following approach has been followed for presenting the environmental and water indicators in the first part, and evaluating the selected methods for achieving the second aim of this project:

1- Environmental indicators are presented in five groups, Climate, Material and Substances flows, Waste management, Water and Environmental economics; and information about unit, temporal coverage and geographical coverage are presented for each indicator.
2- Water indicators for EU countries are presented by this study in five groups (tables) based on the DPSIR framework, Driving force (D), Pressure (P), State (S), Impact (I) and Response (R); and information about unit, temporal coverage, geographical coverage and type are presented for each indicator.
3- Selection of the most four famous methods of evaluating the impacts of freshwater consumption in LCA
4- Description of the selected methods and their characteristics
5- Identification and definition of two groups of criteria and sub-criteria based on the EMInInn project and "framework and requirements for Life Cycle Impact Assessment (LCIA) models and indicators" approach developed by the European Commission
6- Evaluation and Comparison the selected methods based on the identified criteria and sub-criteria
7- Recommendation of the best method

Different steps of this project are summarized in Figure 1.

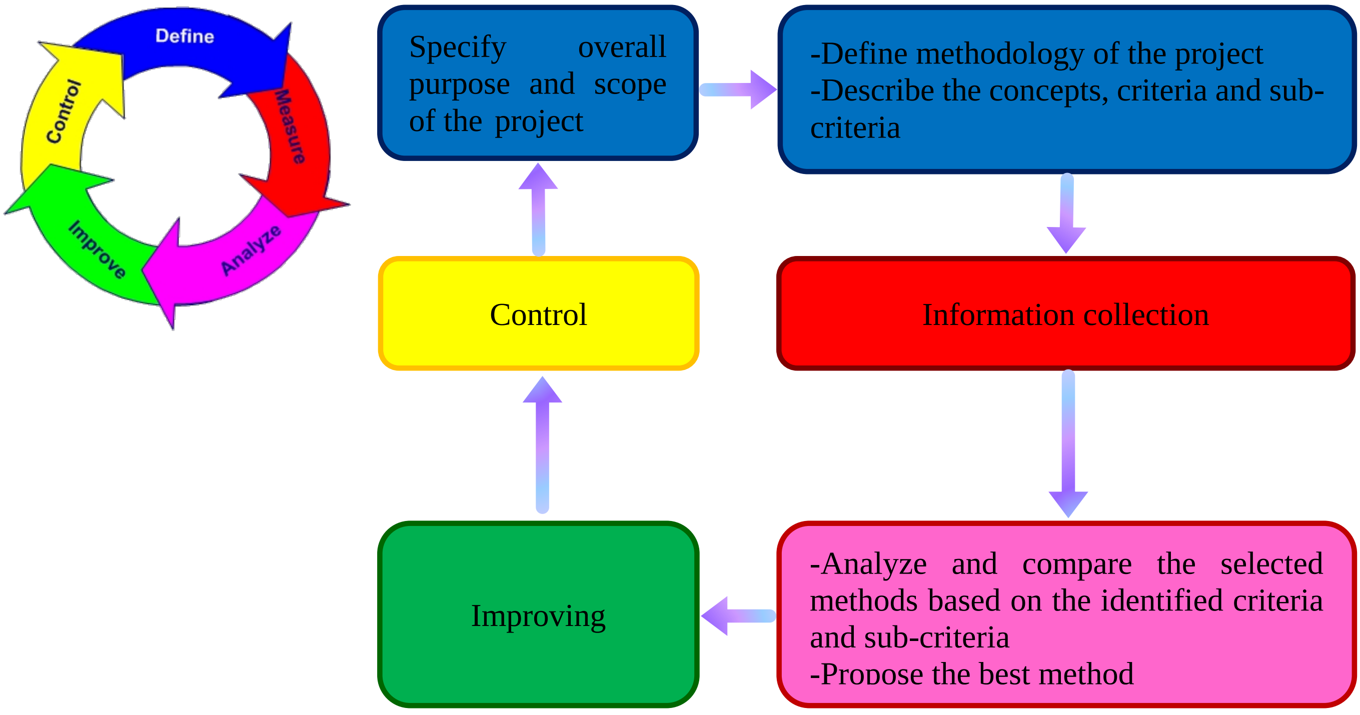

Figure 1. Project steps

4 Indicators for EU countries

In this chapter the indicators for EU countries are presented in two groups as follows:

1- Environmental indicators
2- Water indicators.

4.1. Environmental indicators (for EU countries)

Environmental indicators are presented in five groups (tables) as follows:

1. Climate
2. Material and Substances flows
3. Waste management
4. Water
5. Environmental economics

Table 1. Climate (Eurostat, 2011)

Indicator headline	Unit	Temporal coverage	Geographical coverage
1-CO_2 emissions by economic activity	thousand tonnes	2008-2012	EU-27, Norway
2-Greenhouse gas emissions "from a consumption perspective" per capita	tonnes of CO_2 equivalent per capita	2000-2006	EU-27
3-Carbon stock in forest ecosystems	million metric tonnes	1990-2010	EU27, EFTA

Information:

1-Economic activities are divided into six groups:

-Agriculture, hunting, forestry and fishing

- Manufacturing and construction

- Mining and quarrying, electricity, gas and water supply

- Transport storage and communication

- Households

- Other services: repair of motorcycles, motor vehicles, household and personal goods; financial intermediation; public administration and defense; compulsory social security; other community, personal and social service activities; activities of households as employers of domestic staff; extra-territorial organizations and bodies; real estate, renting and business activities; hotels and restaurants; health and social work; wholesale and retail trade; education (Eurostat, 2011).

2- Three greenhouse gases, Carbone dioxide, Methane and Nitrous oxide are considered by this indicator (Eurostat, 2011).

3- Forests influence the climate by different processes like absorbing carbon into wood, leaves and soil. It remains carbon stock until it is released it into the atmosphere by different processes like decomposition or combustion (Eurostat, 2011).

Forest components are divided into three groups:

-Biomass

-Deadwood

-Soil and litter (Eurostat, 2011)

Table 2. Material and Substances flows (Eurostat, 2011)

Indicator headline	Unit	Temporal coverage	Geographical coverage
1-Raw material input and raw material consumption per capita	tonnes per capita	2007	EU-27
2-Production of environmentally harmful chemicals	million tonnes	1996-2010 2002-2010	EU-15 EU-27
3-Increment and fellings in forests available for wood supply	Several units #	2010	EU27, EFTA
4-Supply balance for wood products	thousand tonnes of carbon	2000,2010	EU-27

Information:

1-Raw materials are divided into four groups:

1.1. Biomass

1.2. Metal ores (gross ores)

1.3. Non metallic

1.4. Fossil energy materials/carriers

Relevant data are presented in two main groups, imports and exports (Eurostat, 2011).

2-Harmful chemical and Non-harmful chemical are divided into different groups based on their effects and impacts:

2.1. Harmful chemical

2.1.1. Severe chronic effects

2.1.2. Significant chronic effects

2.1.3. Moderate chronic effects

2.1.4. Chronic effects

2.1.5. Significant acute effects

2.1.6. Environmentally harmful chemicals, total production (Eurostat, 2011)

2.2. Non-harmful chemical

2.2.1. Chemicals with no environmental impact, total

2.2.2. Chemicals, total production (Eurostat, 2011)

The aggregated production volumes of harmful chemicals for environment include five impact classes.

- Severe chronic (The most harmful).
- Significant chronic
- Moderate chronic

- Chronic
- Significant acute (Eurostat, 2011)

The progress of shifting production from the most harmful to less harmful chemicals for environment is monitored by this indicator.

3- #-Net annual increment

Presented in different ways:

1000 m3 o.b. (over bark, i.e. including the bark)

1000 t C

Year X /year Y (%)

#-Fellings

Relevant data are presented in different ways:

1000 m3 o.b. (over bark, i.e. including the bark)

1000 t C

Year X /year Y (%)

Fellings as percent of net annual increment (%) (Eurostat, 2011)

4-Wood products have been divided into ten main groups and some of them include some subgroups as follows:

4.1. Roundwood

4.1.1. Fuelwood, including wood for charcoal

4.1.2. Industrial roundwood (wood in the rough)

4.2. Wood charcoal

4.3. Wood chips and particles

4.4. Wood residues including pellets

4.5. Sawn wood

4.6. Wood-based panels

4.6.1. Veneer sheet

4.6.2. Plywood

4.6.3. Particle board, OSB and other

4.6.4. Fiber board

4.7. Wood pulp

4.7.1. Mechanical

4.7.2. Semi-chemical

4.7.3. Chemical

4.7.4. Dissolving grades

4.8. Other pulp

4.8.1. Pulp from fibres other than wood

4.8.2. Recovered fibre pulp

4.9. Recovered paper

4.10. Paper and paperboard

4.10.1. Graphic paper

4.10.2. Sanitary and household paper

4.10.3. Packaging materials

4.10.4. Other paper and paperboard NES (Eurostat, 2011)

The relevant information of each group is presented in three different categories

-Production

-Exports

-Imports

A supply balance of wood products has been covered imports plus production minus exports. It shows a measure of the self-sufficiency of wood product for different countries. Since the EU is defined as a single market, only the exports and imports to outside countries of the EU are considered by this indicator (Eurostat, 2011).

Table 3. Waste management (Eurostat, 2011)

Indicator headline	Unit	Temporal coverage	Geographical coverage
1-Total waste generated (hazardous, non-hazardous)	thousand tonnes	2006,2008	EU-27, EFTA (except Iceland and Switzerland), Candidate countries (except Montenegro)
2-Hazardous waste treatment by type	% of total hazardous waste	2008	EU-27 (except Luxembourg and Malta)
3-Waste generation by economic activity	thousand tonnes	2008	EU-27, EFTA (except Iceland), Candidate countries
4-Waste management	thousand tonnes	2008	EU-27, Norway, Candidate countries (except Montenegro)
5-Municipal waste generated per capita	kg per person per year (per capita)	1999-2009	EU-27, EFTA (except Liechtenstein), Candidate countries (except Montenegro)
6-Municipal waste treatment per capita	Kg	1995-2009	EU-27
7-Energy production from municipal waste incineration	thousand tonnes oil equivalent	1999-2009	EU27, EFTA (except Liechtenstein), candidate countries (except Montenegro)
8-Greenhouse gas emissions from waste treatment	thousand tonnes of CO2 equivalent	2009	EU27, EFTA, Turkey
9-Recycling and recovery rate for packaging waste	%	2008	EU27, EFTA (except Iceland and Switzerland)
10-Recycling and recovery rate for end-of-life vehicles	%	2008	EU27 (except Malta), EFTA (except Iceland and CH)

Information:

1-Relevant information has been presented in two groups, hazardous and non-hazardous, separately (Eurostat, 2011).

2- Hazardous waste treatment by type

2.1. Waste treatment divided into different types:

2.1.1 Recovery

2.1.2. Incineration

2.1.3. Disposal

2.1.4. Energy recovery (Eurostat, 2011)

3- Economic activities are divided into six groups:

3.1. Agriculture, hunting, forestry and fishing

3.2. Manufacturing and construction

3.3. Mining and quarrying, electricity, gas and water supply

3.4. Transport storage and communication

3.5. Households

3.6. Other services: repair of motorcycles, motor vehicles, household and personal goods; financial intermediation; public administration and defense; compulsory social security; other community, personal and social service activities; activities of households as employers of domestic staff; extra-territorial organizations and bodies; real estate, renting and business activities; hotels and restaurants; health and social work; wholesale and retail trade; education (Eurostat, 2011).

4-Waste management contains different options:

4.1.Recovery
4.2.Energy recovery
4.3.Incineration
4.4.Disposal (Eurostat, 2011)

5-The amount of municipal waste generated has been presented by this indicator. It includes disposed and waste collected on behalf of or by municipal authorities in the waste management system. There are different sources for this waste stream such as households, commerce, public institutions and offices. The amount of waste generated has been estimated for the areas that are not included in a municipal waste scheme. The information related to the amount of municipal waste treatment has been presented for recycling, treatment operations incineration (with and without energy recovery), consumption and landfilling (Eurostat, 2011).

6-Relevant information of this indicator is presented in different categories:

6.1. Deposit onto or into land

6.2. Material recycling

6.3. Composting

6.4. Incineration (Eurostat, 2011)

8- Relevant Information of this indicator is presented in different groups:

8.1. Landfill

8.2. Wastewater treatment

8.3. Waste incineration (Without energy recovery)

8.4. Other disposal/treatment (Eurostat, 2011)

9- Relevant information about recycling and packaging is presented separately.

10- Relevant information is presented in two categories:

10.1. Reuse and recycling rate

10.2. Reuse and recovery rate (Eurostat, 2011).

Table 4. Water (Eurostat, 2011)

Indicator headline	Unit	Temporal coverage	Geographical coverage
1-Fresh water resources: LTAA (1) — split into external inflow and internal flow	Several units #	P174	EU27, EFTA (except Liechtenstein), Candidate countries (except Montenegro)
2-Total abstraction of fresh water per capita ,last year only, by source	m3	2007-2009 (Varies between countries)	EU27 (except Italy, Austria, Portugal and Finland), EFTA(except Liechtenstein and Norway), Candidate countries (except Montenegro)
3-Use of water from public and self-supply by the domestic sector (households and services) per capita	m3	1990, 1995, 2000, 2005, 2007, 2009	EU27 (except Estonia, Ireland, Slovakia, Finland and United kingdom), EFTA (except Iceland and Liechtenstein), candidate countries (except Montenegro)
4-Self-supply water use for energy production (cooling water only)	Several Units #	1990, 1995, 2000, 2005, 2007, 2009	EU27 (except Denmark, Ireland, France, Italy, Cyprus, Malta, Portugal, Romania, Slovenia, Slovakia and United Kingdom), EFTA (except Liechtenstein and Norway), candidate countries (except Montenegro and Croatia)
5-Population connected to at least secondary wastewater treatment	% of national resident population)	1990, 1995, 2000 2005, 2007, 2009	EU27 (except Slovakia), EFTA (except Liechtenstein) and Turkey

Information:

1-LTAA (Long term annual average (>20 years)
#-Water resources (millionm3/year)

#- Water resources per capita (m3/year)

The relevant information of each of these two groups is presented in three categories as follows:

1.1. Internal flow

1.2. Actual external flow

1.3. Total fresh water sources

Renewable fresh water resources are described as sum of the actual external inflow and internal fellow. Internal flow refers to the volume of precipitation minus the evapotranspiration by plants and the evaporation from surfaces (Eurostat, 2011).

Actual external inflow is the water inflow from neighboring territories. In absolute values, water resources of different countries show significant variations that can be because of different factors such as hydrology (position in river basins) and climate. Also per capita values varied considerably among countries, according to their hydrology and geography, population density (Eurostat, 2011).

2-Fresh water sources are divided into three categories:

2.1. Fresh surface water

2.2. Fresh groundwater

2.3. Total fresh water abstraction (Eurostat, 2011)

4-Self-supply water use for energy production (cooling water only)

#Water use for energy production (cooling purposes) — share of total water use in the country (%)

#Water use for energy production (cooling water) per capita (m3) (Eurostat, 2011)

Table 5. Environmental economics (Eurostat, 2011)

Indicator headline	Unit	Temporal coverage	Geographical coverage
1-Environmental taxes by revenue type	Several units #	2009	EU27, EFTA(except Liechtenstein and Switzerland)
2-Energy taxes by economic activity, last year only	thousand EUR	2005, 2007 and 2008 (varies between countries)	EU27 (except Estonia, Ireland, Greece, France, Cyprus, Latvia, Hungry, Poland, Portugal, Romania, Slovenia, Slovakia, Finland) and Norway
3-Transport taxes by economic activity, last year only	thousand EUR	2006-2008 (varies between countries)	EU27 (except Bulgaria, Estonia, Ireland, Greece, France, Cyprus, Latvia, Hungry, Poland, Portugal, Romania, Slovenia, Slovakia, Finland) and Norway
4-Pollution/resource taxes by economic activity, last year only	thousand EUR	2006-2008 (varies between countries)	EU27 (except Bulgaria, Germany, Estonia, Ireland, Greece, France, Cyprus, Latvia, Luxembourg, Hungry, Poland, Portugal, Romania, Slovenia, Slovakia, Finland) and Norway
5-Implicit tax rate on energy, last year only	EUR per toe	1999, 2000, 2006, 2007, 2008 and 2009 (varies between countries)	EU27, EFTA (except Liechtenstein and Switzerland)
6-Environmental protection investment and current expenditure by sector, last year only	million EUR	1998, 1999, 2002, 2003, 2007, 2008 and 2009 (varies between countries)	EU27, EFTA, Candidate countries
7-Environmental protection expenditure by environmental domain, last year only	million EUR	1998, 1999, 2002, 2003, 2007, 2008 and 2009 (varies between countries)	EU27, EFTA (except Liechtenstein), Candidate countries (except Montenegro and FYR of Macedonia)
8-Pollution prevention investments of manufacturing sector	million EUR	2002, 2003, 2004 2005, 2006, 2007 2008 and 2009	EU27 (except Denmark, Germany, Ireland, Luxembourg and Malta), EFTA (except Iceland and Liechtenstein) and Croatia

Information:

1-A total environmental tax is presented in two main groups with two different units:

1.1. Million EUR" and

1.2. % of GDP

There are seven subgroups for each of them as follows:

-Energy taxes

-Transport taxes

-Taxes on pollution/resources

-Total environmental taxes

-Energy taxes

-Transport taxes

-Taxes on pollution/resources (Eurostat, 2011)

2-Economic activities include seven groups:

2.1. Agriculture, hunting, forestry and fishing

2.2. Manufacturing and construction

2.3. Mining and quarrying, electricity, gas and water supply

2.4. Transport storage and communication

2.5. Households

2.6. Other services: repair of motorcycles, motor vehicles, household and personal goods; financial intermediation; public administration and defense; compulsory social security; other community, personal and social service activities; activities of households as employers of domestic staff; extra-territorial organizations and bodies; real estate, renting and business activities; hotels and restaurants; health and social work; wholesale and retail trade; education

2.7. Not allocated (Eurostat, 2011)

3-Economic activities are divided into different groups:

3.1. Agriculture, hunting, forestry and fishing

3.2. Manufacturing and construction

3.3. Mining and quarrying, electricity, gas and water supply

3.4. Transport storage and communication

3.5. Households

3.6. Other services: Repair of motorcycles, motor vehicles and household and personal goods; Financial intermediation and Real estate; community services and public administration; activities of households as employers; Wholesale and retail trade; Hotels and restaurants; extraterritorial organizations.

3.7. Not allocated (Eurostat, 2011)

4-Economic activities are divided into different groups:

4.1. Agriculture, hunting, forestry and fishing

4.2. Manufacturing and construction

4.3. Mining and quarrying, electricity, gas and water supply

4.4. Transport storage and communication

4.5. Households

4.6. Other services: repair of motorcycles, motor vehicles, household and personal goods; financial intermediation; public administration and defense; compulsory social security; other community, personal and social service activities; activities of households as employers of domestic staff; extra-territorial organizations and bodies; real estate, renting and business activities; hotels and restaurants; health and social work; wholesale and retail trade; education.

4.7. Not allocated (Eurostat, 2011)

5- Implicit tax rate on energy (ITR) is defined as the ratio between two factors, energy tax revenues and final energy consumption. It is explained for the taxes levied of the use of energy that can be considered as an indicator for measuring fostering energy efficiency (Eurostat, 2011).

6-Information of this indicator is presented in three main groups and some subgroups for each of them as follows:

6.1. Industry

6.1.1. Total investment

6.1.2. Total current expenditure

6.2. Specialized producers

6.2.1. Total investment

6.2.2. Total current expenditure

6.3. General government

6.3.1. Total investment

6.3.2. Total current expenditure (Eurostat, 2011)

7- Information is presented in four domains:

7.1. Protection of air and climate

7.2. Wastewater management

7.3. Waste management

7.4. Other domains (Eurostat, 2011)

8- Pollution prevention investments are capital expenditure on modification of existing, or new technologies, methods, equipment, processes (or parts thereof) which are designed to reduce or prevent the amount of pollution generated at the source, so the environmental impacts reduction is associated with the polluting activities and/ or release of pollutants (Eurostat, 2011).

4.2. Water indicators (for EU countries)

Water indicators for EU countries are categorized by Eurostat in five groups based on the DPSIR framework as follows:

1. Driving force (D)
2. Pressure (P)
3. State (S)
4. Impact (I)
5. Response (R)

The last column of the tables in this section shows the type of each indicator.

According to Eurostat there are two types:

1-Type A – What is happening to the environment and to humans?

2-Type B – Does it matter?

Table 6. Driving force (EEA, 2011)

Indicator headline	Unit	Temporal coverage	Geographical coverage	Type
1-Discharge of oil from refineries and offshore installations	tonnes	1990-2004 No data for 1991 and 1993.	Data available only from Denmark, Germany, Ireland, the Netherlands, United Kingdom and Norway; hence coverage is restricted to the northeast Atlantic;	---
2-Residues from combustion of coal for energy production	Mt/yr	1993-2004	EU-15	----
3-Emissions of nitrogen (N) and phosphorus (P) from urban wastewater treatment (UWWT) plants	t/year	1970, 1980, 1990, 2000	Notes: Only countries with data from all periods included the number of countries in parentheses. Nordic: Norway, Sweden and Finland. Central Europe: Austria, Netherlands and Switzerland. AC: Hungary and Czech Republic	---

Information:

1- Offshore installation is one of the most important pollution sources through water produced (main source) and spills and drilling muds and cutting. They can cause smothering of marine biota and surface contamination, and the oil chemical components can have long-term impacts and acute toxic effects, also disposal of cuttings contaminated with chemicals and oil in the immediate vicinity of the installations, damage the benthic biodiversity close to the installations by toxic contamination and imposing anoxia (EEA, 2011).

2- Residues from coal combustion present information of the coal quality used for use of pollution abatement technologies and for power generation. The residues handling can have low environmental impact if they are disposed of and utilized in an environmentally safe way, but unsafe disposal, utilization and storage has water pollution risks (EEA, 2011).

3- Urban waste water is one of the most important contributors to phosphorus discharges, and to a lesser extent nitrogen discharges. Estimating the quantities of discharges of nitrogen and phosphorus can be applied to calculate pressures on the environment. A high level of emissions shows a high pressure on quality of water that can have the stimulating eutrophication effect (EEA, 2011).

Table 7. Pressure (EEA, 2011)

Indicator headline	Unit	Temporal coverage	Geographical coverage	Typology
1-Nitrogen oxides (NOx) emissions	ktonnes (1000 tonnes)	1990-2010	EEA32	Performance indicator (Type B – Does it matter?)
2-Ammonia (NH3) emissions	ktonnes (1000 tonnes)	1990-2010	EEA32	Performance indicator (Type B – Does it matter?)
3-Sulphur dioxide SO2 emissions	ktonnes (1000 tonnes)	1990-2010	EEA32	Performance indicator (Type B – Does it matter?)
4-Aquaculture production	Production is measured in thousand tonnes, while marine aquaculture production relative to coastline length is given in tonnes/km.	1990-2008	EEA32	Descriptive indicator (Type A – What is happening to the environment and to humans?)
5-Specific air pollutant emissions	For passenger transport, specific emissions are expressed in grams of pollutant (NOx, VOC, PM, CO)	1995, 2009	EU27, Norway, Switzerland, Turkey	Descriptive indicator (Type A – What is happening to the environment and to humans?)

	per passenger-kilometer. For freight transport, specific emissions are expressed in grams of pollutant (NOx, VOC, PM, CO) per tonne-kilometer.			
6-Use of freshwater resources	Water exploitation index - WEI (%); water abstraction for irrigation, public water supply, manufacturing industry and energy cooling (mio. m3 per year).	1990-1992, 1994-1995, 1997-2007	EEA32	Descriptive indicator (Type A – What is happening to the environment and to humans?)
7-Freshwater quality	The concentration of nitrate is expressed as mg nitrate (NO3)/l for groundwater and mg nitrate-nitrogen (mg NO3-N/l) for rivers and orthophosphate and total phosphorus as mg P/l.	1992-2006	Table 7	N/A
8-Aquaculture: effluent water quality from finfish farms	No units have been specified	1990-2006	EU25, EFTA4, Albania, Croatia, Turkey	N/A
9-Gross nutrient balance	Kilogram per year (kg/year) per hectare (ha)	1990, 2000	EU15	Descriptive indicator (Type A – What is happening to the environment and to humans?)
10-Emissions of organic matter	emission of BOD (t/year)	1990, 1995, 2000	Nordic: Norway, Sweden, Finland, Iceland.	---

			Central Europe: England & Wales and Northern Ireland, Netherlands and Switzerland. AC: Estonia, Hungary and Czech Republic	
11-Invasive alien species in Europe	No units have been specified	1900-2008	EEA32 and Table 7	N/A
12-Loads of hazardous substances to coastal waters	Inputs relative to 1990-1992	1990-1992 1993-1997 1998-2001	North-East Atlantic	---
13-Fishing fleet capacity	The size of the European fishing fleet is presented as numbers of vessels, the capacity as the total engine power, given in kW and the gross tonnage (GT) given in tonnes. Average size is a derived measured given in GT/vessel.	1998-2008	EU15, EFTA4, Bulgaria, Cyprus, Estonia, Latvia, Lithuania, Malta, Poland, Romania, Slovenia	Descriptive indicator (Type A – What is happening to the environment and to humans?)
14-Agriculture: nitrogen balance	No units have been specified	1990-2004	Table 7	N/A
15-External costs and charges per vehicle type	Description of external cost	2007	EU27	Descriptive indicator (Type A – What is happening to the environment and to humans?)

Information:

1- NOx (nitrogen oxides) includes nitrogen dioxide (NO2) and Nitric oxide (NO).They can cause eutrophication and acid deposition which have potential to change the water and soil quality (EEA, 2011).

For more information about NOx (nitrogen oxides) emissions from different sectors, refer to table 8.

2- Emission of Ammonia has potential to change the water and soil quality by causing eutrophication and acid deposition (EEA, 2011).

For more information about Ammonia (NH_3) emissions from different sectors, refer to table 8.

3- Sulphur dioxide (SO_2) is a pollutant that causes eutrophication and acid deposition which have potential to change the water and soil quality (EEA, 2011).

For more information about Sulphur dioxide (SO_2) emissions from different sectors, refer to table 8.

4- This indicator express the quantity of the development of aquaculture production in Europe by major country and sea area as well as the share of nutrients aquaculture discharges relative to the total nutrients discharges into coastal zones (EEA, 2011).

5- NOx, VOC, PM and CO are the pollutants which are considered by this indicator and transportation is one of the most important source of these pollutants (EEA, 2012).

The indicator is selected to monitor the different impacts of the stricter emission standards on the identified emissions of air pollutants related to the various freight and passenger transport modes (EEA, 2011).

The amount of emissions of air pollutants from freight and passenger transport are identified by:

- Fleet composition (type and number of vehicles)
- Vehicle utilization (load factors and occupancy rates)
- Driving characteristics (distances and speeds).

Specific emissions are emissions of pollutants per transport unit, passenger-km or tonne-km, which is indicated by mode (rail, road, inland, air, maritime) (EEA, 2011).

6- Water abstraction which presents the percentage of the resources of freshwater, provides a helpful picture, at the country level, of the resource pressures in a simple and understandable manner, also it presents trends over time. This indicator identifies how total water abstraction causes pressure on different water resources by indicating countries with high abstraction in connection with the resources and so prone to water stress. Changes in water exploitation index (WEI) helps to analyze the fact of how changes of abstraction influence freshwater resources by making them more sustainable or increasing pressure on them (EEA, 2011).

The water exploitation index (WEI) is identified as the mean of annual total abstraction for freshwater which is divided by the mean annual total renewable freshwater resources at the national level, it is presented in percentage terms (EEA, 2011).

7-This indicator reflects:

- Quality of water that fundamentally identifies the functioning and structure of aquatic and associated terrestrial organisms and ecosystems.

- Annual median concentrations of Ammonium (NH_4) and Biological Oxygen Demand (BOD) in rivers.

- Trends of the nitrate and orthophosphate concentration in rivers, total nitrate and phosphorus in lakes, and nitrate concentration in groundwater bodies (EEA, 2011).

8- This indicator shows the annual trend in discharge of nutrients in the marine environment due to aquaculture practices (EEA, 2011).

9- The indicator calculates the potential nitrogen surplus on agricultural land. This is done by estimating the balance between nitrogen added and removed from agricultural system per hectare of agricultural land (EEA, 2011).

The indicator considers all inputs and outputs of the farm. The input includes the amount of nitrogen from animal manure and mineral fertilizers. As well as deposition from the air, fixation of nitrogen by legumes, and other minor sources. Nitrogen output includes harvested crops, or crops and gross eaten by livestock (some escaped nitrogen to the atmosphere like N_2O is difficult to calculate so not taken into account) (EEA, 2011).

10- COD, BOD and TOC are applied as key indicators of the water oxygen content. The environmental pressure related to discharges from waste water treatment plants of urban area can be calculated from the quantities of discharges to the environment over a year, calculated through measurements at the discharge point or other methods applying some factors such as, agricultural runoff and industrial effluents, emission factors, and including data on scattered and non-connected and population (if available). High levels show a high pressure on quality of water resources that can have the effect on reduction of biodiversity in aquatic communities and reduction of microbiological quality (EEA, 2011).

11- The indicator includes two elements:

1-“Cumulative number of alien species in Europe since 1900”, which presents trends in species that have potential to become invasive alien species.

It is founded in Europe from 1900 and it has been estimated in 10-year intervals. Introductions of Pre-1900 are also estimated. Relevant Information is divided into major ecosystems (marine, terrestrial and freshwater) and identified 'taxonomic' groups: invertebrates, vertebrates, primary producers (bryophytes, vascular plants, and algae) and fungi (EEA, 2011).

2-“Worst invasive alien species threatening biodiversity in Europe”, a list includes invasive species which have demonstrated negative impacts (EEA, 2011).

The list of these spices in Europe presents a number of the most dangerous invasive alien species in Europe, across major taxonomic groups and ecosystems, with respect to relevant impacts upon European biodiversity and changing abundance or range. This list includes the pan-European area (EEA, 2011).

Two criteria have been used to select species of the list:

1-The species with a serious adverse impact on biological diversity in Europe

There is lack of quantitative data in this case so selecting of species for this list is according to the expert view rather than quantifiable data so it is a subject to debate (EEA, 2011).

2-The species, in addition to its adverse biodiversity impact, can have negative impact on health, human activities, and/or economic interests (EEA, 2011).

12- It comprises riverine and direct inputs of mercury, lindane, cadmium, PCB and lead into the North-East Atlantic.

The aim of this indicator is to convey the trends and levels of hazardous substances in inputs of European seas. The monitored load of hazardous substances may be harmful to marine ecosystems (EEA, 2011).

The lack of reliable or consistent data from the EEA counties or marine conventions does not allow adequate assessment of trends and concentrations of hazardous substances of marine water in European area (EEA, 2011).

13- The indicator is an estimation of the capacity and size of the fishing fleet; it includes the vessels average sizes, which in turn are supposed to approximate to the environment and the pressure on fish resources in marine (EEA, 2011).

14-"Gross nitrogen balance" calculates the potential surplus for nitrogen in agricultural land. This is estimated by calculation from the balance between removed nitrogen in the system per hectare of agricultural land and added nitrogen in an agricultural system (nitrogen input may be taken as a proxy indicator for the general intensity of agricultural management). The indicator estimates all inputs to and outputs from the farm, so it includes nitrogen input (EEA, 2011).

15- The external costs of transportation are the cost which affecting environment, society and economy, but they are not directly created by the transport users who have caused them (e.g. air pollution, noise, climate change, accidents, infrastructure, etc.) (EEA, 2011).

Table 8. The European emission data in Table 7 are specified for the following sectors (EEA, 2011)

Sectors Emissions	Nitrogen oxides(NOX)	Ammonia(NH3)	Sulphur dioxide(SO2)
1-Energy production and distribution	**X**	**X**	**X**
2- Energy use in industry	**X**	**X**	**X**
3- Industrial processes	**X**	**X**	**X**
4- Road transport	**X**	**X**	**X**
5- Non-road transport	**X**	**X**	**X**
6-Comercial, institutional and households	**X**	**X**	**X**
7- Solvent and product use	**X**	**X**	**X**
8- Agriculture	**X**	**X**	**X**
9- Waste	**X**	**X**	**X**
10- Other	**X**	**X**	**X**

Table 9. State (EEA, 2011)

Indicator headline	Unit	Temporal coverage	Geographical coverage	Typology
1-Chlorophyll in transitional, coastal and marine waters	The concentration of chlorophyll-a is expressed as microgram /l in the uppermost 10 m of the water column during summer.	1985-2009	Table 10	Descriptive indicator (Type A – What is happening to the environment and to humans?)
2-Nutrients in transitional, coastal and marine waters	Concentrations in microgram mol/l	1985-2008	Table 10	Descriptive indicator (Type A – What is happening to the environment and to humans?)
3-Nutrients in freshwater	The concentration of nitrate is expressed as mg nitrate (NO3)/l for groundwater and mg nitrate-nitrogen (mg NO3-N/l) for rivers and orthophosphate and total phosphorus as mg P/l.	1992-2008	Table 10	Descriptive indicator (Type A – What is happening to the environment and to humans?)
4-Oxygen consuming substances in rivers	Annual average BOD after 5 or 7 days incubation (BOD5/BOD7) is expressed in mg O2/l and annual average total ammonium concentrations in micrograms N/l.	1992-2008	EEA32, Albania, Macedonia the former Yugoslavian Republic of	Descriptive indicator (Type A – What is happening to the environment and to humans?)
5-Bathing water quality	The data are expressed in terms of percentage of inland and coastal bathing waters complying with the mandatory standards and guide levels for microbiological and physicochemical parameters (assessment under Directive 76/160/EEC) and with the mandatory	1990-2009	EU27, EFTA4, Croatia	Performance indicator (Type B – Does it matter?)

	standard for Escherichia coli and guide levels for both microbiological parameters (assessment during transition period).			
6-Biological quality of lakes	Cyanobacteria (% of phytoplankton biomass)	1988-93, 1994-98, 2001, 2002, 1985	Denmark, France, Greece, Norway,	---
7-Pesticides in Groundwater	µg/l	http://www.eea.europa.eu/data-and-maps/indicators/pesticides-in-groundwater/whs1a_pesticidesgroundwater_110504.pdf/at_download/file	Table 10	---
8-Hazardous substances in rivers	Concentration relative to standards	1990-2001	http://www.eea.europa.eu/data-and-maps/indicators/hazardous-substances-in-rivers/whs2_hazardoussubstancesrivers_180504.pdf/at_download/file	---
9-Hazardous substances in lakes	µg/l	1995	Nordic countries	---
10-Nitrogen concentrations in rivers	Nitrat or TON mg N/l	1990-1998	Germany, Denmark, France, Netherlands, United Kingdom	---
11-Use of freshwater resources	Water exploitation index [%, i.e. percent of water withdrawn related to water available] Water availability [m3/year] Water abstraction, water withdrawals [m3/year] Water availability index [m3/person/year]	2000-2030	Table 10	Descriptive indicator (Type A – What is happening to the environment and to humans?)

	Change in water availability, water withdrawals [% change relative to base-year]			
12-Exposure of ecosystems to acidification, eutrophication and ozone	Eutrophication and acidification * Regions at risk: % of total sensitive ecosystem area * Critical loads/threshold, depositions, exceedance: - Acidifying equivalents (H+) per hectare and year (eq H+.ha-1.a-1) - Eutrophication equivalents (N) per hectare and year(eq N.ha-1.a-1) * Change over time: % of change compared to base year. Ozone * Regions at risk: % of total agricultural area * Change over time: % of change compared to base year. * Percentage of the arable land in Europe potentially exposed to ambient air concentrations of ozone (O3) in excess of the EU target value set for the protection of vegetation.	1996-2007, 2010, 2020	EU27, EFTA4, Albania, Bosnia and Herzegovina, Croatia, Macedonia the former Yugoslavian Republic of, Montenegro, Serbia	Performance indicator (Type B – Does it matter?)

Information:

1- The aim of this indicator is to present the effects of measures taken to decrease discharges of phosphate and nitrogen on phytoplankton (chlorophyll-a) coastal concentrations. This indicator is applied for indicating of eutrophication (EEA, 2011).

The indicator presents geographical distribution and trends of surface concentrations of chlorophyll-a (microgram/l) in mean summer for regional seas in Europe area (EEA, 2011).

EEA (2011) defined relevant terms in this way:

"Summer period is:

- June to September for stations north of latitude 59 degrees in the Baltic Sea (Gulf of Bothnia and Gulf of Finland)

- May to September for all other stations

The following sea areas are covered:

- Baltic: The HELCOM area including the Belt Sea and the Kattegat

- North Sea: The OSPAR Greater North Sea including the Skagerrak and the Channel, but not the Kattegat

- Atlantic: The north-east Atlantic including the Celtic Seas, the Bay of Biscay and the Iberian coast

- Mediterranean: The whole Mediterranean

- Black Sea: The whole Black Sea" (EEA, 2011)

2- The N/P ratio can provide good information about the potential phosphorus or nitrogen limitation of the primary production of phytoplankton (EEA, 2011).

This indicator shows overall trends of phosphate and nitrate concentration (microgram/l) in winter and N/P ratio (it is based on molar concentrations) in Europe for the regional seas (EEA, 2011).

EEA (2011) defined relevant terms in this way:

"Winter period is:

- January, February and March for stations east of longitude 15 degrees (Bornholm) in the Baltic Sea

- January and February for all other stations.

The following sea areas are covered:

- Baltic: The HELCOM area including the Belt Sea and the Kattegat

- North Sea: The OSPAR Greater North Sea including the Skagerrak and the Channel, but not the Kattegat

- Atlantic: The north-east Atlantic including the Celtic Seas, the Bay of Biscay and the Iberian coast

- Mediterranean: The whole Mediterranean

- Black Sea: The whole Black Sea" (EEA, 2011)

3- The indicator shows the concentrations of nitrates and orthophosphate in rivers, nitrate in groundwater, and total phosphorus in lakes. It can be used for illustrating geographical variations in current concentrations of nutrient and temporal trends (EEA, 2011).

4- Large input of organic matter (decaying organic waste and microbes) can cause reduction in biological and chemical quality of river water, damaged microbiological contamination and aquatic biodiversity communities can affect the bathing and drinking water quality (EEA, 2011).

Discharging of organic pollution from agricultural run-off, wastewater treatment plants and industrial effluents causes higher metabolic processes rates that need oxygen and it could lead to the increasing of water zones with anaerobic condition and without oxygen (EEA, 2011).

The biochemical oxygen demand (BOD) is the key indicator for the status of the oxygenation in water. This indicator illustrates the trends and current situation by regarding concentrations of ammonium (NH_4) and BOD in rivers (EEA, 2011).

5- This indicator presents the changes of the designated bathing waters(coastal and inland) quality over the time in Europe, European sea regions , European countries and EU in terms of compliance with microbiological parameters standards(total coliforms and faecal coliforms) and physicochemical parameters (phenols , surface-active substances and mineral oils) identified by the Bathing Water Directive of EU(76/160/EEC) and also with microbiological parameters standards (intestinal enterococci and Escherichia coli) which is presented by the New Bathing Water Directive (2006/7/EC) (EEA, 2011).

6- In the management of lakes in the river basin districts, the community of phytoplankton will be used as a quality element. This quality element is applied with other quality elements to assess the progress of achieving the good ecological status and the objectives of the river basin management plans (EEA, 2011).

7- Generally there is lack of reliable data and information on pesticides in groundwater in Europe area (EEA, 2011).

8- Heavy metals comprised: copper, cadmium; lead (all identified countries); nickel and zinc (all identified countries) mercury (NL, AT, SE, GB only) nickel and zinc.

Pesticides comprised: dieldrin (GB only), atrazine (all 3 countries); simazine (all 3 countries) lindane (GB and SL).

Other organic substances: benzo-g, h, i-perylene (GB and SL) and: fluoranthene (all 3 countries) (EEA, 2011).

Information combined from impact, representative, reference and flux stations.

The annual average concentration of a country and substance has been initially estimated and compared to relevant standards of water quality. The average of relative concentrations is considered for each of the three groups of substances to identify a potential general assessment of the environmental ‘burden’ which is arisen from hazardous substances (EEA, 2011).

9- There is a sub-indicator for this indicator called “Concentrations of hazardous substances in lake fish” (EEA, 2012).

10- TNO (Total oxidized nitrogen) is the sum of nitrite and nitrate. TON is monitored by some countries instead of nitrate. Nitrate levels are often much higher than nitrite therefore for the aim of this assessment, TON and nitrate are regarded to be approximately equivalent (EEA, 2011).

11- The water exploitation index (WEI) is defined as the annual total abstraction of freshwater which is divided by the annual total renewable freshwater resource; it is presented in percentage terms. The indicator can be applied preferably by risen base or at the national level. If the water exploitation index for a region exceeds 20%, it is identified as a region being under water stress and if it exceeds 40%, it is identified as a region under severe water stress. The indicator combines data on water withdrawals and water availability, and is thus also referred to as withdrawals-to-availability index (EEA, 2011).

Alternatively, the underlying data may be used (i.e. data on water withdrawals and water availability for an agricultural use, industrial use, domestic use respectively) to indicate separately (EEA, 2011).

The water availability index is the average of freshwater resources which is available per person at country level or river basins. If this value is below 1000 m3 per person (however consider population as a proxy in water usage is less accurate) this region can be identified as water scarce (EEA, 2011).

Changing in annual water availability shows changing in freshwater resources at the country level or river basin over an identified time period, primarily because of changes in climate change or upstream water use (EEA, 2011).

Change in annual water abstraction shows change in water use at the country level or river basin over an identified time period. Changes may be presented for different socio-economic activities separately, i.e. water for manufacturing processes and electricity production, domestic use, and for agricultural activities (EEA, 2011).

12- This indicator presents the crop or ecosystem areas with the risk of exposure to harmful air pollution levels or loads. Ground-level ozone eutrophying and acidifying air pollutants are identified, including possible changes in future for Europe area according to scenario analyses. The risk is calculated based on the 'critical load' for eutrophication and acidification and 'critical level' for sensitive (semi-) agricultural areas or natural ecosystems for ozone. The risks are estimated as a quantitative factor of the exposure to identified pollutants below which do not have harmful and significant effects in the long term. This estimation is based on the present information and knowledge (EEA, 2011).

Eutrophication and acidification

Critical loads of nutrient nitrogen and acidity are applied to explain exposure to eutrophication and acidification for semi-natural areas and forests in Europe, involving Natura 2000 sites. The areas with exceedance of critical loads of deposition of eutrophying and acidifying pollutants are described as the European ecosystem areas which are at risk of biodiversity damage. By analyzing the exceedances change of over time (comparative static analysis) and identification of the effects of air pollutant emissions, changing over time is identified (EEA, 2011).

Ozone

“Accumulated ozone exposure over a threshold of 40 ppb” (AOT40-value) is identified for this indicator according to Air Quality Directive (2008/50/EC). This indicator shows the crop or ecosystems at risk of exposure to ozone from air pollution at harmful levels. The indicator estimates relevant risk by referring to the ozone of sensitive area for “critical level”. Therefore, the indicator shows the quantitative estimation of the exposure to ozone below which harmful and significant effects and it does not occur in the long term based on present knowledge (EEA, 2011).

Table 10. Geographical coverage of some of the state indicators in Table 9 (EEA, 2011)

	Chlorophyll in costal, transitional, and marine waters	Nutrients in costal, transitional, and marine waters	Nutrients in freshwater	Urban waste water treatment	Freshwater quality	Water retention	Water requirement
Albania	X	-	X	-	X	X	X
Andorra					-	-	-
Armenia					-	-	-
Austria	-	-	X	X	X	-	-
Azerbaijan					-	-	-
Belarus							X
Belgium	X	X	X	X	X	-	-
Bosnia and Herzegovina	X	-	-	-	-	X	X
Bulgaria	X	-	X	X	X	X	-
Croatia	X	X	-	-	-	-	X
Cyprus	X	X	-	X	-	-	-
Czech Republic	-	-	X	X	X	-	-
Denmark	X	X	X	X	X	-	-
Estonia	X	X	X	X	X	-	-
Finland	X	X	X	X	X	-	-
France	X	X	X	X	X	-	-
Georgia					-	-	-
Germany	X	X	X	X	X	-	-
Greece	X	X	-	X	-	-	-
Hungary	-	-	X	X	X	-	-
Iceland	X	-	-	X	-	-	-
Ireland	X	X	X	X	X	-	-
Italy	X	X	-	-	-	-	-
Kazakhstan					-	-	-
Latvia	X	X	X	X	X	-	-
Liechtenstein	-	-	X	-	X	-	-
Lithuania	X	X	X	X	X	-	-
Luxembourg	-	-	X	X	X	-	-
Macedonia the former Yugoslavian Republic of	-	-	-	-	X	X	X
Malta	X	-	-	X	-	-	-
Moldova Republic of				-	-	-	-
Monaco				-	-	-	-
Montenegro	X	-	-	-	-	X	X
Netherlands	X	X	X	X	X	-	-
Norway	X	X	X	X	X	X	-
Poland	X	X	X	X	X	-	-
Portugal	X	-	X	X	X	-	-

Romania	X	-	-	X	-	-	-
Russian Federation	X	-	-	-	-	-	X
San Marino				-	-	-	-
Serbia	X	-	-	-	-	X	X
Slovakia	-	-	X	X	X	-	-
Slovenia	X	-	X	X	X	-	-
Spain	X	-	X	X	X	-	-
Sweden	X	X	X	X	X	-	-
Switzerland		-	X	X	-	X	X
Turkey	X	-	-	X	-	-	X
Ukraine			-	-	-	-	-
United Kingdom	X	X	X	X	X	-	X

Country indicator	Water and food-borne diseases	Northward movement of marine species	Pesticides in Groundwater	Invasive alien species in Europe	National river classification schemes	Agriculture: nitrogen balance**	Use of freshwater resources
Albania	-	-	-	X	X	-	-
Andorra				X	-	-	-
Armenia				X	-	-	-
Austria	-	-	X	-	X	X	X
Azerbaijan				X	-	-	-
Belarus	-	-	-	X	-	-	-
Belgium	-	X	X	-	-	X	X
Bosnia and Herzegovina	-	-	-	X	-	-	-
Bulgaria	-	-	X	-	-	-	-
Croatia	-	-	-	X	-	-	-
Cyprus	-	-	-	-	-	-	X
Czech Republic	X	-	X	-	X	X	X
Denmark	X	X	X	-	-	X	X
Estonia	X	-	-	-	-	-	X
Finland	-	-	X	-	-	X	X
France	-	X	X	-	X	X	X
Georgia				X	-	-	-
Germany	-	X	X	-	X	X	X
Greece	-	-	X	-	-	X	X
Hungary	-	-	X	-	-	X	X
Iceland	-	X	X	-	-	X	X
Ireland	-	X	X	-	X	X	X
Italy	-	-	X	-	-	X	X
Kazakhstan				X	-	-	-
Latvia	-	-	X	-	X	-	X
Liechtenstein	-	-	X	-	-	-	X

Lithuania	-	-	X	-	-	-	X
Luxembourg	-	-	X	-	X	X	X
Macedonia the former Yugoslavia Republic of	-	-	-	X	-	-	-
Malta	-	-	-	-	-	-	X
Moldova Republic of				X	-	-	-
Monaco				X	-	-	-
Montenegro	-	-	-	X	-	-	-
Netherlands	X	X	X	-	-	X	X
Norway	-	X	X	-	-	X	X
Poland	X	-	X	-	X	X	X
Portugal	-	X	X	-	-	X	X
Romania	-	-	X	-	X	-	-
Russian Federation	-	-	-	X	-	-	-
San Marino				X	-	-	-
Serbia	-	-	-	X	-	-	-
Slovakia	-	-	X	-	-	X	X
Slovenia	X	-	X	-	X	-	X
Spain	X	X	X	-	X	X	X
Sweden	-	-	X	-	-	X	X
Switzerland	X	-	-	-	-	X	X
Turkey	-	-	-	-	-	X	-
Ukraine				X	-	-	-
United Kingdom	X	X	X	-	X *	X	X

*Northern, Scotland, England and Wales

**For France and Portugal, the data are from 1990 only.

[ ] No Data

[-] No indicator

Table 11. Impact (EEA, 2011)

Indicator headline	Unit	Temporal coverage	Geographical coverage	Typology
1-Water temperature	0C	1901-2006	Estonia, Finland, Italy, Netherlands	Descriptive indicator (Type A – What is happening to the environment and to humans?)
2-Water retention	http://www.eea.europa.eu/publications/eea_report_2008_4/pp111-148CC2008_ch5-7to9_Terrestrial_ecosystems_soil_and_agriculture.pdf	1961-2080	EU27 and Table 10	Descriptive indicator (Type A – What is happening to the environment and to humans?)
3-Water requirement	http://www.eea.europa.eu/publications/eea_report_2008_4/pp111-148CC2008_ch5-7to9_Terrestrial_ecosystems_soil_and_agriculture.pdf	1975-2007	EU27 and Table10	Descriptive indicator (Type A – What is happening to the environment and to humans?)
4-Water and food-borne diseases	http://www.eea.europa.eu/publications/eea_report_2008_4/pp149-160CC2008_ch5-10_Human_Health.pdf	2008	Table 10	Descriptive indicator (Type A – What is happening to the environment and to humans?)
5-Northward movement of marine species	http://www.eea.europa.eu/publications/eea_report_2008_4/pp76-110CC2008_ch5-4to6_Water_quantity_and_quality.pdf	1958-2005	Table 10	Descriptive indicator (Type A – What is happening to the environment and to humans?)
6-Freshwater biodiversity and water quality	http://www.eea.europa.eu/publications/eea_report_2008_4/pp76-110CC2008_ch5-4to6_Water_quantity_and_quality.pdf	1956, 1960-1970, 1980-2008	EU27	Descriptive indicator (Type A – What is happening to the environment and to humans?)
7-National river classification schemes	% change per year of reporting period		Table 10	---
8-Storms and storm surges in Europe	http://www.eea.europa.eu/publications/eea_	1881-2005, 2050	EU27, Norway	Descriptive indicator (Type A – What is happening to the

	report_2008_4/pp37-75CC2008_ch5-1to4_Athmosphere_and-_cryosphere.pdf			environment and to humans?)
9-Sea level rise	http://www.eea.europa.eu/publications/eea_report_2008_4/pp76-110CC2008_ch5-4to6_Water_quantity_and_quality.pdf	1992-2009	EU27	Descriptive indicator (Type A – What is happening to the environment and to humans?)
10-River flow	http://www.eea.europa.eu/publications/eea_report_2008_4/pp76-110CC2008_ch5-4to6_Water_quantity_and_quality.pdf	1900-1998, 2071-2098	EU27, Switzerland	Descriptive indicator (Type A – What is happening to the environment and to humans?)
11-Normalized losses from river flood disasters	http://www.eea.europa.eu/publications/eea_report_2008_4/pp161-192CC2008Ch6_7Adaptation_Consequences.pdf	1961-2005, 2071-2098	EU27	Descriptive indicator (Type A – What is happening to the environment and to humans?)

Information:

1- The indicator shows Water temperatures in four identified European lakes and rivers in the 20th century (1-River Rhine in Lobith 2- River Danube in Vienna 3-Lake Saimaa in Finland 4-Lake Võrtsjärv in Estonia) (EEA, 2011).

2- Soil water retention is the most important hydraulic property of the soil that controls functioning of soil in ecosystems and extremely affects soil management.

The indicator shows the relevant information of Modelled summer soil moisture (1961-1990) and planned changes (2070-2080) in Europe (EEA, 2011).

3- Climate change can effect on agricultural activities primary by changing rainfall and rising temperature trough increasing CO2 emission. A Reduction in rainfall, as a demand for crop growth, causes increase in the requirement of irrigation water, which has some negative economic and environmental impacts. Increasing the water shortage in these areas causes increase in the competition between different sectors (agriculture, tourism, energy, etc.) (EEA, 2011)

The indicator presents information related to:

1-Rate of the meteorological water balance change (1975-2007)

2-Meteorological water balance in identified parts over Europe (1975-2007) (EEA, 2011)

4- The indicator indicates percentage change in weekly salmonella cases by increasing temperature (1 0C) (EEA, 2011)

There are four main issues should be regarded for assessing the relationship between exposure to rainfall changes and availability of water and quality and health outcomes:

1-Relatioship between water availability, access of household to improved water and the health burden because of diarrhoeal diseases;

2-Extreme rainfall (drought or intense rainfall) role in facilitating outbreaks of water-borne;

3- Temperature and runoff effects on chemical and microbiological contamination of recreational, coastal and surface waters;

4-Temperature direct effects on the incidence of different diseases like diarrhoeal. Climate change and variability also change the risks of pest and fire and pathogen outbreaks, with negative results for forestry, fibre and food (EEA, 2011).

5- This indicator reflects:

-Two tropical fish was recorded between 1963-1996

-Zooplankton northward movement between1958-2005

-Relative abundance of flatfish species in Warm-water to cold-water (EEA, 2011)

6- The indicator indicates:

-Northward shift and relevant changes in occurrence of identified freshwater species.

-Model simulation for phytoplankton dynamics and hydrodynamics during specified time (three contrasting summers) in Lake Nieuwe Meer of Netherlands.

-The Trichoptera taxa sensitive share in climate change of the European Ecoregions (EEA, 2011).

7- There are different types of schemes but they cannot really be compared therefore the graph has been divided into the classification types applied (physic-chemical, biological, combined).There are more than one national classification scheme for some countries and so the relevant results for each scheme are presented separately e.g. Wales and England has a biological and chemical scheme. The separation into scheme types also illustrates that while one scheme may present a quality improvement, another may present deterioration e.g. the chemical scheme of Northern Ireland presented an improvement while the biological scheme presented deterioration (EEA, 2011).

According to EEA (2011) there is a sub-indicator for this indicator which shows “length of river classified as a percentage of the total length of river in the country” (EEA, 2011).

8- The indicator shows:

-Storm index for different Europe parts (1881-2005)

-Relative change in the period time of 1961-2000 and 2050 for annual maximum daily mean wind speed by using different models

-Change of the height of “a 50-year return period extreme water level event” because of different scenarios at the end of 21st century (EEA, 2011).

9- This indicator presents:

-Changes in sea-level at European tide-gauge stations (1896-2004)

-Global sea level changes (1870-2006)

-Changes in sea-level in Europe (October 1992-May 2007)

-Projected global average rise in Sea-level (1990-2100) (EEA, 2011)

10- The indicator identifies:

-Modelled change of annual river flow (1971-1998 and 1900-1970)

-Projected change of annual river and mean seasonal flow (the reference period 1961-1990 and 2071-2100)

-Projected change of daily average river flow (the reference period 1961-1990 and 2071-2100) (EEA, 2011)

11- This indicator shows:

-Losses of flood per thousand of GDP in the EU (1970-2005)

-Number of casualties in the results of flood disasters in the EU (1970-2005)

-Projected change in damage from river floods with a 100-year return period (2071-2100 and 1961-1990) (EEA, 2011)

Table 12. Response (EEA, 2011)

Indicator headline	Unit	Temporal coverage	Geographical coverage	DPSIR
1-Urban waste water treatment	Percentages of population connected to primary, secondary and tertiary wastewater treatment.	1980, 1985, 1990-2007	Table 10	Descriptive indicator (Type A – What is happening to the environment and to humans?)
2-Urban waste water treatment	1) Percentages of population connected to urban wastewater treatment; 2) Kg of nitrogen and phosphorous per inhabitant per year.	2005, 2008-2015 (objectives of the UWWT directives)	Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, Netherlands, Poland, Portugal, Slovenia, Spain, Sweden	Descriptive indicator (Type A – What is happening to the environment and to humans?)
3-Renewable electricity consumption	Electricity generation is measured in either GWh or TWh (1000 GWh). The share of electricity generated from renewable energy sources is express as percentage.	1990-2008, 2010	EU27, Iceland, Norway, Russian Federation, Switzerland, Turkey	Performance indicator (Type B – Does it matter?)
4-Renewable primary energy consumption	Both, renewable energy and total primary energy consumption are measured in thousand tonnes of oil equivalent (ktoe). Therefore, the amount of renewable energy is measured in absolute value, but will be presented in the form of a percentage.	1990-2008	EU27, Iceland, Norway, Russian Federation, Switzerland, Turkey	Performance indicator (Type B – Does it matter?)

Information:

1-The indicator shows the percentage of population which is connected to primary, secondary and tertiary wastewater treatment plants also it shows the success of different policies for reducing the pollution from wastewater by defining the trends of the percentage of the population which is connected to the public wastewater treatment plants (different purification levels are includes) (EEA, 2011).

The indicator illustrates:

1- Changes in wastewater treatment in Europe area since 1980s;

2- Conformity by Member States in terms of preparing tertiary treatment with the requirement to provide (until 31 December 1998) severe treatment about agglomerations with more than 10000 p.e. (population equivalent) which are discharged into sensitive areas;

3- Urban wastewater treatment level for large cities of EU countries (agglomerations >150 000 p.e.) (EEA, 2011).

2- Households and Industry wastewaters have a significant pressure on the water resources because of the nutrients and organic matter load and hazardous substances.

This indicator indicates percentage of population that is connected to wastewater treatment plants (primary, secondary and tertiary) (EEA, 2011).

The indicator presents:

1- Current and possible future changes of level (according to UWWT directive) of population, depended to primary, secondary, and tertiary urban wastewater treatment;

2- Current and future changes level (according to UWWT directive) of nitrogen and phosphorous discharge from different wastewater treatment plants (EEA, 2011)

Water Model from EEA/ETC is used by this indicator.

3-The ratio between the production of electricity by renewable energy sources and consumption of gross national electricity identified as percentage of share of the renewable electricity. It calculates the contribution of production of electricity by renewable energy sources to the consumption of national gross electricity (EEA, 2011).

Sources of Renewable energy are identified as sources of renewable non-fossil energy: biogas, biomass, geothermal, landfill gas, tidal, sewage treatment plant gas, wave, hydropower, solar and wind. Electricity production of renewable energy sources includes the electricity generation of hydro plants (excluding produced as from pumping storage systems), wind, electricity, solar and geothermal from biomass/wastes. Electricity from biomass/wastes includes electricity generation of wood/wood wastes and the combustion other solid wastes from a renewable nature (black liquor, straw), biogas (incl. sewage, landfill, and farm gas), and incineration of municipal solid waste and liquid biofuels. Consumption of gross national electricity includes generation of total gross national electricity from all fuels (including autoproduction), plus imports of electricity, minus electricity exports (EEA, 2011).

4- The quota of consumption of renewable energy is the ratio between consumption of gross inland of energy of renewable sources(TOE) and total consumption of gross inland energy (TOE), expressed as percentage for a calendar year. Both total energy consumption and renewable energy are identified in thousand tonnes of oil equivalent (ktoe) (EEA, 2011).

Sources of Renewable energy are identified as sources of renewable non-fossil energy: biogas, biomass, geothermal, landfill gas, tidal, sewage treatment plant gas, wave, hydropower, solar and wind (EEA, 2011).

5 Four Methods of evaluating the impacts of freshwater use in LCA

Milà i Canals et al. method (2009), Pfister et al. method (2009), Ecological Scarcity method (2006), and Water footprint method (2011) are the four methods of evaluating the impacts of freshwater use in LCA, which are evaluated by this study.

The descriptions of four selected methods are presented in this chapter.

5.1. Milà i Canals et al. method (2009)

This method was developed by Milà I Canals et al. (2009) for evaluating the impacts of freshwater use, including abstractions such as irrigation (Arnøy, 2012).

Two types of water are considered by this method:

1–Blue water (ground and surface water), including fossil blue water (non-renewable ground water)

2–Green water (moisture of soil) (Berger and Finkbeiner, 2010a)

The system boundary of this method is defined by the river basin, and flows from other watersheds are not included (Flury et al., 2011, Berger and Finkbeiner, 2010b).

The following impact pathways related to water use are considered by this method:

• Aquifer groundwater and fossil use over renewability rate ⟶ reducing the freshwater availability as a future generation's resource (freshwater depletion (FD))

• Water use ⟶ insufficient availability of fresh water ⟶ effects on quality of ecosystem (freshwater ecosystem impacts (FEI))

• Changes in land use⟶Changes in the cycle of water (runoff and infiltration)

⟶freshwater availability changes⟶effects on quality of ecosystem quality (freshwater ecosystem impacts (FEI)) (Berger and Finkbeiner, 2010b)

This method suggested that water use contributes to two impact categories and presents an indicator for each of these: FD is the indicator for the impact abiotic resource depletion, while land use effects and their impacts on freshwater ecosystems are indicated by FEI (Berger and Finkbeiner, 2010b).

Freshwater ecosystem impact (FEI)

The Freshwater ecosystem impact is an indicator for assessing the freshwater availability changes, and presents the mass or volume of “ecosystem-equivalent” water, referring to the mass or volume of water likely to be affecting freshwater ecosystems. This indicator accounts for changes in different water abstractions such as irrigation and its effects on the quality of ecosystem in a specific region (MilàiCanals et al., 2010).

The calculation of FEI takes into account evaporative use of blue water in aquifers and surface water. The use of fossil blue water is not accounted for, however, because fossil water does not have an important ecological function. Changing water use because of land use changes is accounted for, because it can affect the runoff and infiltration of water (Berger and Finkbeiner, 2010b).

When FEI considers irrigation, the formula is as follows:

$$FEI = IW*CF \qquad (1)$$

IW is the amount of irrigated water consumed

CF is the characterization factor (Hospido et al., 2011)

Two different indicators have been applied by different researchers as characterization factors:

1-WUPR (The Water Use Per Resource)

2- WSI (The Water Stress Indicator)

WUPR identifies the level of water stress so it is a proper indicator for evaluating the potential impacts which can affect the aquatic ecosystem. The result of this indicator indicates the percentage of water availability for other uses than for human uses (Milà i Canals et al., 2009).

FAO Aquastat database has provided relevant data for this indicator for most countries (Eléonore, 2010).

To be more precise, WUPR is calculated based on the total freshwater withdrawal for human uses in region i (WU_i) and the “available renewable water supply” in region i (WR_i) (Hospido et al., 2011).

$$\boldsymbol{WUPR} = \frac{\boldsymbol{WU_i}}{\boldsymbol{WR_i}} \qquad (\mathbf{2})$$

The ratio indicates the percentage of available water that is used for human purposes and, hence, the percentage available for the ecosystem (Eléonore, 2010, Berger and Finkbeiner, 2010, Milà i Canals et al., 2010).

Smakhtin et al. (2004) suggested using WSI as a more accurate indicator for assessing the environmental water stress. The WSI is obtained through adding the environmental water requirement (EWR) to the WUPR formula (Milà i Canals et al., 2009).

Smakhtin, Carmen Revenga et al. (2003) described EWR in this way "Environmental water requirements are defined as the quality and quantity of water required by an aquatic ecosystem for the protection and maintenance of its structure, functioning and dependent species" (Smakhtin et al., 2003).

$$\boldsymbol{WSI_i} = \frac{\boldsymbol{WU_i}}{\boldsymbol{WR_i - EWR_i}} \qquad (\mathbf{3})$$

The WSI is applied by Mila i Canals et al. (2009) for assessing impacts of water stress on ecosystems and obtaining the characterization factors. Even though WSI is a more accurate indicator in comparison with WUPR, still in some cases WUPR is applied instead of WSI due to lack of data (Milà i Canals et al., 2009).

There are four methods for estimating the EWR, including hydraulic rating, hydrological rules, habitat simulation, and holistic. However all of these methods need data that are sometimes difficult to obtain (Bald and Scholz, 2007, D. Walker and Hunt, 2009).

Freshwater Depletion (FD)

Freshwater is an abiotic resource. It can be depleted, if the water use is greater than the renewability rate of the affected water resources. Mila i Canals et al. suggested that the approach of Guinée et al. (2002) for quantifying depletion of abiotic resources should be adapted to resources of freshwater. This approach is called the Abiotic Depletion Potential (ADP). (Eléonore, 2010).

Since the renewability of surface water resources, like rivers, is usually high, only the water consumption from renewable aquifers (evaporative use) and water of fossil (non-evaporative and evaporative use) is accounted for in this impact category (Berger and Finkbeiner, 2010a).

ADP (eq/kg) is calculated by subtracting the regeneration rate from the resource extraction rate, and dividing that with the resource ultimate reserve squared. The result is an indication of how long the current resources will last. The result of the first part of this equation is then multiplied with the ultimate reserves of the reference resource antimony squared and divided by the depletion rate for the reference resource antimony (Sb) (Berger and Finkbeiner, 2010a, Milà i Canals et al., 2009).

$$\boldsymbol{ADP_i = \frac{ER_i - RR_i}{(R_i)^2} \cdot \frac{(R_{Sb})^2}{DR_{Sb}}} \qquad (\mathbf{4})$$

$\boldsymbol{ER_i}$ is the extraction rate of resource i (m^3/y)

$\boldsymbol{RR_i}$ is the regeneration rate of resource i

$\boldsymbol{R_i}$ is the resource ultimate reserve in resource i (m^3/y)

$\boldsymbol{R}_{Sb}$ is the ultimate reserves of the reference resource antimony

$\boldsymbol{DR}_{Sb}$ is annual depletion rate for the reference resource antimony (Sb)

(Berger and Finkbeiner, 2010a, Sundberg, 2012)

5.2. Pfister et al. method (2009)

Pfister et al. (2009) developed a method for assessing the impacts of freshwater consumption on both midpoint and endpoint levels. This method considers three protection areas: resources, ecosystem quality, and human health. Consumptive use of blue water is assessed by this method, and the geographical system boundary of the assessment is the watershed area (Arnøy, 2012, Flury et al., 2011).

Water stress index (WSI)

Water stress index (WSI) is an indicator applied by this method for the assessment of environmental issues on both endpoint and midpoint level. Note that the WSI introduced here is different from the WSI that is applied by Mila i Canals and colleagues, which is a characterization factor in impact category of FEI (freshwater ecosystem Impact) (Berger and Finkbeiner, 2010a).

The Water stress index (WSI) is calculated according to the following function in order to reach characterization factors that vary continuously from 0.01 to 1 (Berger and Finkbeiner, 2010a).

$$\boldsymbol{WSI} = \frac{\mathbf{1}}{\mathbf{1} + \boldsymbol{e}^{-6.4 \cdot \boldsymbol{WTA}*}\left(\frac{\mathbf{1}}{\mathbf{0.01}} - \mathbf{1}\right)} \qquad (\mathbf{5})$$

Blue water consumption is multiplied by the specific WSI at regional level to obtain the characterized results (Berger and Finkbeiner, 2010a).

Withdrawal-to-availability (WTA) ratio is applied to calculate the characterization factors for water consumption and water use. It is calculated according to the following equation:

$$\boldsymbol{WTA_i} = \frac{\sum_j \boldsymbol{W_{i,j}}}{\boldsymbol{A_i}} \qquad (\mathbf{6})$$

This equation shows the ratio of total annual freshwater withdrawal for human uses in a specific region (W) to annually available water supply in that region (A).

j is human use

i is a region

The hydrologic situation at the regional level varies in a year because of differences in seasonal precipitation. The seasonal variation can cause water stress if storage from wet seasons is not enough to fully compensate the water resources for dry seasons. By considering a Variation Factor (VF), these effects are considered in the calculation and involved in the modified WTA (withdrawal to availability) ratio (WTA*) (Berger and Finkbeiner, 2010a).

$$WTA^* = \begin{cases} \sqrt{VF} \times WTA & \text{for highly regulated watersheds} \\ VF \times WTA & \text{for watersheds with little regulation} \end{cases} \quad (7)$$

WTA is Withdrawal to availability

VF is Variability in precipitation

(Pfister, 2010)

Different endpoints impacts

Three endpoint impacts are accounted for by this method: human health, ecosystem quality, and resources. This assessment is implemented based on the eco-indicator 99 framework (Berger and Finkbeiner, 2010a).

1- Human health

In the area of human health protection, the Pfister et al. method (2009) refers to the malnutrition impact pathway caused by shortage of water for irrigation. A cause-effect-chain is modeled to quantify the human health damage due to malnutrition as a consequence of water consumption in a specific region according to the following equation: (Berger and Finkbeiner, 2010a)

$$\Delta HH_{malnutr,i} = \underbrace{\underbrace{WSI_i \cdot WU_{\%agriculture,i}}_{WDF_i} \cdot \underbrace{HDF_{malnutr,i} \cdot WR_{malnutr,i}{}^{-1}}_{EF_i} \cdot DF_{malnutr,i}}_{CF_{malnutr,i}} \cdot WU_{consumptive,i} \quad (8)$$

WSI is the Water Stress Index.

WU $_{\%agriculture,i}$ is the fraction of total water use that is used in agriculture.

$\boldsymbol{WDF_i}$ is the water deprivation factor (m^3 deprived/m^3 consumed) in region i. It is the water deprivation for agricultural purposes, and it is quantified by multiplying WSI and WU% agriculture factors.

HDF $_{malnutrition}$ is the human development factor. This factor is estimated based on the Human Development Index (HDI), which takes ranks countries based on three aspects:

education, life expectancy, and income indices. There is a reversed relationship between HDF and HDI. Countries with the smaller HDI have the bigger HDF, and smaller HDF belongs to countries which are included in the list of “very high development countries” (UNDP, 2013).

$\boldsymbol{WR}_{malnutrition}$ is the water requirement to prevent malnutrition (m^3/year/person).

$\boldsymbol{EF_i}$ is an effect factor (capita *yr/m^3 deprived) in region i. Annual number of malnourished people per water quantity deprived. It is calculated by dividing the $HFD_{malnutrition}$ by the $WR_{malnutrition}$.

$\boldsymbol{DF}_{malnutrition}$ is the damage factor. It shows damages caused by malnutrition (DALY year /person).

$\boldsymbol{CF}_{malnutrition}$ is the characterization factor for human health damage. It identifies the expected damage if an additional water unit is consumed (DALY/m^3).

$\boldsymbol{WU}_{consumptive}$ is water consumption in a particular region (m^3).

Note: $WR_{malnutrition}$ and DF malnutrition are independent from the geographical location but HDF is a value estimated for each country.

(Pfister, 2010, Berger and Finkbeiner, 2010a)

2- Ecosystem

In order to calculate the damage of freshwater consumption on the ecosystem quality, the ecological cause-effect-chain should be modeled. They use the effects on vegetation growth as indicator or proxy for the damage to ecosystems. The damage to ecosystem quality is determined according to the following equation: (Berger and Finkbeiner, 2010a)

$$\Delta EQ = CF_{EQ} \cdot WU_{consumption} = \underbrace{NPP_{wat-lim}}_{PDF} \cdot \underbrace{\frac{WU_{consumptive}}{P}}_{A.t} \qquad (9)$$

Δ***EQ*** is ecosystem damage factor/potential ($m2*yr/m^3$). It is the characterization factor for damages to quality of ecosystems ($m2/m^3$ in one year).

P shows annual rainfalls mean (m/year)

NPP $_{wat-lim}$ is the fraction of the Net Primary Production which is limited in growth by availability of reduced precipitation/water. It shows the water shortage vulnerability of the ecosystem.

PDF is potentially disappeared fraction (of vegetation)

WU $_{consumptive}$ is consumptive water use (m^3)

P is precipitation (m/yr)

A*t is theoretical area-time equivalent which is needed to recover the consumed amount of water through natural precipitation

(Berger and Finkbeiner, 2010a, Pfister, 2010)

3- Resources

Freshwater depletion can be caused by fossil water extraction or water bodies' overexploitation. The principle of back-up technologies has been employed to calculate damages of resource depletion. The method estimates the energy quantities needed to reestablish the quality of freshwater. Desalination plants can be considered as the back-up technology in the case of freshwater (Eléonore, 2010).

The damage to resources is calculated by multiplying the ***WU***$_{consumptive}$ (water consumption), ***E*** $_{desalination}$ (the desalination energy demand) and the fraction of consumption of water contributing to ***F*** $_{depletion}$ (freshwater depletion) (Berger and Finkbeiner, 2010a).

$$\Delta R_i = E_{desalination} \cdot F_{deletion} \cdot WU_{consumption} \qquad (10)$$

$$F_{depletion} = \begin{cases} \frac{WTA_i - 1}{WTA_i} & for\ WTA_i > 1 \\ 0 & for\ WTA_i \leq 1 \end{cases} \qquad (11)$$

(Berger and Finkbeiner, 2010a)

Aggregating endpoint impacts

Calculating the damage of consumption of freshwater on human health, ecosystem quality, and resources, and then weighting and normalizing according to weighting factors in the eco-indicator 99 method can be accomplished to reach a single-score indicator. This indicator is a measure of the overall damage caused by freshwater consumption. It can be compared and aggregated to damage from other environmental interventions such as waste or emissions, which are caused by the product system investigated (Berger and Finkbeiner, 2010a, Pfister, 2010).

5.3. Ecological Scarcity Method (2006 and 2008)

The Ecological Scarcity method, also called “Swiss Ecopoints” and “Swiss Ecoscarcity”, was first introduced in 1990 for environmental assessment related to a broad range of resources such as freshwater, and updated in 1997. The Swiss version of this method was extended and updated in 2006 and finalized in 2008. New environmental targets, legislation and developments in Switzerland have been taken into account by this updated version (Arnøy, 2012, Milà i Canals et al., 2009, ESU-services, 2013).

The aim of this method is to provide weighting and characterization factors for different extractions and emissions, based on objectives and targets of the public policy. It has attempted to provide a well-established method according to the environmental policy framework, which includes international treaties and can be applied as a reference framework to optimize and improve processes and individual products (JRC-IES, 2010, ESU-services, 2013).

The Ecological scarcity method can be applied for environmental assessment of specific processes and products. Besides, it is often applied as an element in environmental management systems (EMS) of different companies, where weighting method supports the environmental assessment of the company (ISO 14001). This method was published in 1990 in Switzerland and the first update and the amendment was provided in 1997 (JRC-IES, 2010).

Calculation of eco-factors

This method allows weighting of several environmental interventions by applying eco-factors. It includes common approaches in characterization /classification for ozone depletion, climate change, acidification, pesticides, cancer due to radionuclides, primary energy resources, endocrine disruptors, and biodiversity losses due to land use. Other interventions are considered individually, such as various heavy metals, or in a group e.g. NM-VOC. (JRC-IES, 2010).

The eco-factors are calculated by considering the actual flows of pollutants and resources, as well as the maximum allowed or critical flows. It can be described as a method that considers the distance to the specific political targets and objectives rather than the actual environmental damages. On the other hand, the damages to ecosystem quality and human health should be considered in the process of target setting of the general environmental policy. This is why policy can serve as a basis for the critical flows. The eco-factors have been originally formed for Switzerland but in recent years some new eco-factors have been defined for other countries such as Japan and Belgium (Flury et al., 2011, JRC-IES, 2010).

The eco-factors are presented in eco-points, which can be added up to a single-score indicator of the overall environmental impacts of the product or process investigated without addressing any specific damages to ecosystems and human health (Berger and Finkbeiner, 2010a, Pfister, 2011).

Eco-factors are calculated according to the following steps and equation and expressed as EP (Eco-point)/m3 or EP/kg:

1-characterization

2-normalization

3-weighting

(Frischknecht et al., 2009b, Grinberg et al., 2012)

$$\textit{Eco-factor} = \frac{1EP}{F_k} \cdot \frac{F}{F_k} \cdot c \qquad (12)$$

$$1EP \cdot \underbrace{K}_{\text{Characterization (optional)}} \cdot \underbrace{\frac{1}{F}}_{\text{Normalisation}} \cdot \underbrace{\left[\frac{F}{F_k}\right]^2}_{\text{Weighting}} \cdot \underbrace{c}_{\text{Constant(1.12UBP/a)}} \qquad (13)$$

EP is eco-point (the unit).

F is current flow.

F_k is critical flow.

(Frischknecht et al., 2009a)

For water use, the eco-factor is related to the index of water stress from OECD, which is equal to Consumption / Available water (precipitation + inflows – evaporation) (Flury et al., 2011).

This method provides eco factors not only for evaporation use but also for water use (Arnøy, 2012).

The system boundary of the eco-factor is the boundary of the watershed and country level. Due to lack of data it cannot be applied at all locations of the world (Pfister and Hellweg, 2011, Flury et al., 2011).

1- Characterization

No characterization is performed in the calculation of eco-factors for water use. This means that different water sources are not characterized based on their type and quality (Berger and Finkbeiner, 2010a).

2- Normalization

In normalization, the contribution of a pollutant unit or resource use related to the product or process is divided by the total current pressure/load in a specific region (for example for the whole of a country) per year (ESU-services, 2013).

3- Weighting

Weighting factors for different emissions (into air, top-soil/groundwater and water) as well as for consumption of various resources are supplied by this method (JRC-IES, 2010).

$$\boldsymbol{Weighting} = \left(\frac{current\ flow}{critical\ flow}\right)^{2} = \left(\frac{total\ annual freshwater\ withdrawal\ for\ human\ uses(W)}{annually\ available\ renewable\ water\ supply(A)\cdot 20\%}\right)^{2} = (\boldsymbol{WTA})^{2} \cdot \left(\frac{1}{20\%}\right)^{2} \quad (14)$$

The current flow is defined as the total annual freshwater withdrawal for human consumption (W) in the specific region or a country, and the critical flow is equal to 20% of the total annual available renewable water supply for this region. WTA is withdrawal to availability (Berger and Finkbeiner, 2010a).

In weighting for assessment of water use, this method incorporates the relevant political objective of preventing water stress. The OECD measures the scarcity (pressure on the fresh-water resources) by calculation of the ratio of the water consumption (irrigation, industrial use drinking water) to the available resources of renewable water. If this is 20%, it is regarded as an acceptable pressure. (Frischknecht et al., 2009a, Berger and Finkbeiner, 2010a)Version 2006 of this method presented a new approach for assessing the freshwater resources. The freshwater resources assessment has applied regionalization. Since freshwater is defined as a scarce resource in some countries and regions so the regional differences should be taken in to account in the assessment (Frischknecht et al., 2009a).

5.4. Water footprint method (2011)

ISO 14046 (2011) has defined water footprint in this way "A water footprint study addressed the environmental aspects and impacts of a product, process or organization" (ISO, 2011).

Water footprint is one of the water use indicators, which considers both indirect and direct water use of a producer or a consumer (WFN, 2013).

The virtual water concept was proposed by Allan in 1960, and it was the first effort for footprinting the water use in production. The method considered all water quantities consumed in the production processes. It assesses both the use of water in the actual processes of manufacturing and the use of water in background processes, e.g. energy or raw material production (Berger and Finkbeiner, 2010a).

The water footprint method presented by Hoekstra in 2002 relies on the concept of virtual water, but this method in addition considers temporal and spatial information (Berger and Finkbeiner, 2010a).

The water footprint provides information about issues such as water contamination and shortage throughout the entire production process for services and goods (including distribution) (Smallwat11, 2011).

Different scales of water footprint

All three types of water (blue, green and grey) are considered by this method. The system boundary of the assessment is at the watershed, and it can be distinguished at global, regional and local level (Kounina et al., 2013).

According to According to Hoekstra, Chapagain et al. (2011) water footprints can be calculated at different levels of scale:

"1-Water footprint of a process step

2- Water footprint of a product

3- Water footprint of a consumer or group of consumers

4- Water footprint within a geographically delineated area

5- National water footprint accounting

6- Water footprint accounting for catchments and river basins

7- Water footprint accounting for municipalities, provinces or other administrative units

8- Water footprint of a business" (Hoekstra et al., 2011)

The most common and relative scales to the aim of this study are explained in next part.

-*Water footprint for individual consumers*

This scale refers to the sum of the freshwater that is directly or indirectly used by a consumer. The volume of water used at home is considered as direct water, and the total freshwater volume used for producing the services and goods and used by consumers is identified as indirect water (Dowd, 2013).

-*Water footprint for businesses*

This is also called "corporate water footprint". It is defined as the total freshwater volume that is consumed indirectly or directly to support and run a business (WFN, 2013).

The water footprint for a business considers two components:

1-The direct use of water by the producer (for manufacturing, producing and supporting activities)

2- The indirect use of water (in the supply chain) (WFN, 2013)

-*Water footprints for nations*

The water footprint for a nation is the volume of water that is consumed for producing the goods and services, which are consumed by the inhabitants (Hoekstra and Chapagain, 2007).

It contains two components:

1- Internal water footprint
2- External water footprint

The internal water footprint refers to the utilization of domestic water resources, and the external water footprint considers the utilization of water resources in other countries (Hoekstra and Chapagain, 2007).

In Japan, about 65% of total water footprint is provided from outside Japan; in China about 7% of the water footprint falls outside of this country (WFN, 2013).

Methodological framework for water footprints

There are some international guidelines for water footprint calculation. They have been maintained by different organization such as Water Footprint Network, UN bodies, NGOs (Non-Governmental Organizations), and corporations.

The Water Footprint Network is an international organization with the mission of analyzing the different impacts (direct and indirect) on water resources from human consumption for encouraging business and national policy-makers to provide a sustainable water management system (Smallwat11, 2011).

According to Hoekstra, Chapagain et al. (2011) a water footprint study consists of the following four main distinct phases:

"1. Setting goals and scope

2. Water footprint accounting

3. Water footprint sustainability assessment

4. Water footprint response formulation" (Hoekstra et al., 2011)

1- Goals and scope

The goal and scope of a water footprint study depends on the aim of the assessment. The study starts with specifying and recognizing the scale of the water footprint.

The goal and scope of an assessment also depend on the target group of people. For example, if the goal of a water footprint is awareness-raising and the target group is the public, estimation of the average water footprints of products in national or global level is probably sufficient but if the purpose is identifying the hotspot for experts, greater details need to be included in the scope and accounting (Hoekstra et al., 2011).

-As described before there are several options for this assessment, such as Water footprint of a product, Water footprint of a process, a specific group of consumer or for a consumer and business. All of these can be also defined in the different geographical scales, for example, water footprint for a specific group of customer in a province, municipality, river basin or a nation.

Identifying the scope is one of the most important steps in the water footprint study. It should be explicit and clear about the 'inventory boundaries' which refers to 'what to exclude' and 'what to include' in an accounting. A functional unit should be identified in this step (Hoekstra et al., 2011).

The following checklist has been suggested by Hoekstra, Chapagain et al. (2011) for setting up a water footprint account:

"• Consider blue, green and/or grey water footprint?

• Where to truncate the analysis when going back along the supply chain?

• Which level of spatiotemporal explication?

• Which period of data?

• For consumers and businesses: consider direct and/or indirect water footprint?

• For nations: consider water footprint within the nation and/or water footprint of national consumption; consider internal and/or external water footprint of national consumption? " (Hoekstra et al., 2011)

The rest of the phases will be described in the next section by using an example of water footprint of a product. This type of water footprint (Water footprint of a product) is considered as an example because it is the most common and useful scale. It has been applied in several case studies, and it can be regarded as a basis for most scales.

2- Water footprint accounting (for a product)

As mentioned before, this scale is defined as the total direct and indirect use of freshwater for production; also the pollution of water is estimated in all production chain steps by calculating of the grey water (Hoekstra et al., 2011).

The procedure of water footprint accounting for industrial sectors, services and different products such as agricultural is similar (Hoekstra et al., 2011).

The water footprint of a product is divided into three types of water use: green, blue and grey (Hoekstra et al., 2011).

The functional unit of water footprint of agricultural products is generally defined in terms of m3/ton or liters/kg; however, in the case of countable agricultural products, it can be determined as a water volume per piece (Hoekstra et al., 2011).

The water footprint of industrial products is often presented in terms of water volume per piece or m3/US$. Other terms can be considered for a water footprint for a product such as water volume/kcal which can be used for products from the food industry. For fuels and electricity, water volume/joule can be applied (Hoekstra et al., 2011).

The origin (input) of the product should be taken into consideration in calculation of water footprint of a product. For example raw materials of a product can be provided in country A, while manufacturing can happen in country B and we have consumption in country C. Circumstances and characteristics of a product and relevant processes can be different in different places, so the production place influences the color and size of the water footprint. Additionally may be one wants to make a geographically map of a final product water footprint, so it is another reason for keeping track of place (Hoekstra et al., 2011).

There are two ways to calculate the water footprint for a product.

1- Chain-summation approach (for specific cases)

2- Stepwise accumulative approach (generic approach) (Hoekstra et al., 2011)

1-The chain-summation approach

This approach is applied only in the specific case where one output product is produced by the production system. In this case the water footprint of a product is calculated according to the following equation: (Hoekstra et al., 2011)

$$\boldsymbol{WF_{prod}[p]} = \frac{\sum_{s=1}^{k} \boldsymbol{WF_{proc}[s]}}{\boldsymbol{P[p]}} \quad [\boldsymbol{volume/mass}] \qquad (\mathbf{15})$$

$WF_{proc}[s]$ is the process of water footprint for step $\boldsymbol{s}$ (volume/time)

$P[p]$ is the product $\boldsymbol{p}$ production quantity (mass/time) (Hoekstra et al., 2011)

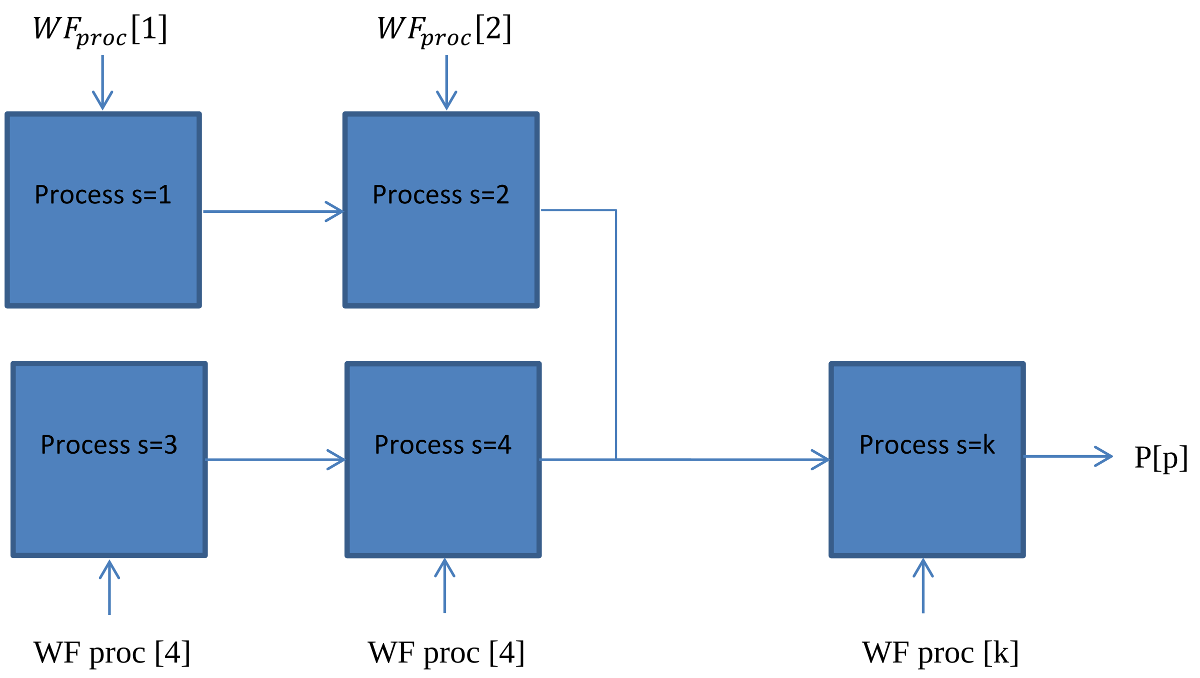

Figure 2. "Schematization of the production system to produce product ***p*** into ***k*** process steps, some steps are in series, others are parallel. The water footprint of output product p is calculated as the sum of the process water footprints of the processes that constitute the production system." Source : (Hoekstra et al., 2011)

In reality, it is rare to find a production system with a single output product only, so a more generic approach for accounting is necessary that can distribute the relevant water uses (Hoekstra et al., 2011).

2-The stepwise accumulative approach

This is a generic way in order to calculate the product water footprint. It is based on the input products' water footprints which are important for the last processing step for producing the product, and the process water footprint of relevant processing step (Hoekstra et al., 2011).

In the case that one output product is produced by many input products, the output product water footprint can be calculated by summing the input product water footprints and then adding the water footprint of processes. But in the case that there is one input product with several output products we need to distribute the input product water footprint to separate relevant products (This is called allocation in LCA). It is done in proportion to the value of the output products (Hoekstra et al., 2011).

The most common case is a product ***p*** with several input products, from i=1 to y and different output products, from p=1 to z (Hoekstra et al., 2011).

The output product water footprint is calculated as:

$$\boldsymbol{WF_{prod}[p]} = \left(\boldsymbol{WF_{proc}[p]} + \sum_{i=1}^{y} \frac{\boldsymbol{WF_{prod}[i]}}{\boldsymbol{f_{p[P,i]}}}\right) \times \boldsymbol{f_{v[P]}} \qquad \textit{[volume/mass]} \qquad (16)$$

WF prod[p] is the output product ***p*** water footprint (volume/mass)

WF prod[i] is the input product ***i*** water footprint (volume/mass)

WF proc[p] is the process water footprint of the processing step that transforms the ***y*** input products into the ***z*** output products, expressed in water use per unit of processed product p (volume/mass)

fp [p,i] is "product fraction"

fv[p] is "value fraction" (Hoekstra et al., 2011)

Note: The process water footprint in the equation is presented in terms of "water volume per unit of processed product"; the given volume should be divided by the relevant "product infraction" for that input product, if the process water footprint is taken per unit of an identified input product (Hoekstra et al., 2011).

$f_{p[P,i]}$ [mass/mass] is the product fraction for the output product ***p*** which is processed from the input product. It is identified as the output product quantity ($w[p]$, mass) divided by the input product quantity ($w[i]$, mass): (Hoekstra et al., 2011)

$$\boldsymbol{f_{p[P,i]}} = \frac{\boldsymbol{w[p]}}{\boldsymbol{w[i]}} \qquad [-] \qquad (\mathbf{17})$$

$f_{v[P]}$ is the value fraction of the output product ***p*** (monetary unit/monetary unit). It is identified as the product market value divided by the aggregated market value of all the outputs products that are produced obtained from the input products: (Hoekstra et al., 2011)

$$\boldsymbol{f_{v[P]}} = \frac{\boldsymbol{price[p]} \times \boldsymbol{w[p]}}{\sum_{p=1}^{z}(\boldsymbol{price[p]} \times \boldsymbol{w[p]})} \qquad [-] \qquad (\mathbf{18})$$

$price[p]$ is the product ***p*** price (monetary unit/mass) (Hoekstra et al., 2011)

The denominator of this equation is sum of the output products from 1 to z that come from the input products (Hoekstra et al., 2011).

Note: "price" here is considered as an indicator for the product economic value, which is not always the case, for example if the market of the product is distorted or in a case of no market for specific product the real economic value can be taken (Hoekstra et al., 2011).

In a simple case that only one input product is processed into only one output product, estimation of the output product water footprint becomes simpler: (Hoekstra et al., 2011)

$$\boldsymbol{WF_{prod}[p] = WF_{proc}[p] + \frac{WF_{prod}[i]}{f_{p[P,i]}}} \quad [\boldsymbol{volume/mass}] \qquad (\mathbf{19})$$

For calculating the final product water footprint for a production system, it is the best way to start with calculating the most original resources' water footprints. Thus it is started by the supply chain and then calculating the intermediated products' water footprints step-by-step to the water footprint of the final product. Finally total components are distributed over the different output products, based on their value fractions and product fractions (Hoekstra et al., 2011).

Product fractions can be taken from the available literature for an identified production process. For example the product fraction of the livestock and crop products can be found in Chapagain and Hoekstra (2004, vol 2) and FAO (2003) (Hoekstra et al., 2011).

3- Water footprint sustainability assessment (for a product)

For getting an idea about the meaning of the footprint size, experts compare the relevant water footprint to the available resources of freshwater which is expressed in m3/yr. In of the step Water footprint sustainability Assessment, the human water footprint is compared to the amount of freshwater that can be sustainably supported by the Earth. There are several alternatives related to this assessment, which should be clarified and considered according to the aim of the project. For example, sustainability has three dimensions (social, environmental and economic); there are two levels for formulating the impacts, primary and secondary impacts, and the water footprint can have different colours (blue, green, grey) (Hoekstra et al., 2011).

The water footprint of different scales (product, producer or consumer) depends on the geographical region and usually the water footprint of one specific scale cannot have a major impact and creates the water scarcity and pollution problems. Thus these different impacts emerge as a cumulative effect of all different activities and are considered in as assessment (Hoekstra et al., 2011).

The sum of different water footprints of different process steps for production is defined as the water footprint of a product. Therefore the water footprint sustainability of the product depends on the water footprints sustainability of the different process steps and each of them are calculated for a specific time. Thus water footprint of a product includes several separated components, which each of them refers to a specific process and time (Hoekstra et al., 2011).

According to Hoekstra, Chapagain et al. (2011) every separated component can be assessed in phase of sustainability assessment based on two questions:

"1. Is the water footprint component located in a catchment area and period of the year that was identified as a hotspot?

2. Is the water foo
3. tprint of the process itself unsustainable: in other words, can the water footprint be avoided altogether or reduced at reasonable societal cost?" (Hoekstra et al., 2011)

Hoekstra, Chapagain et al. (2011) described hotspot in this way" A hotspot is a specific period of the year (for example, the dry period) in a specific (sub) catchment in which the water footprint is unsustainable." In other worlds, "Hotspots are the places where and periods within the year when water footprints are not sustainable and thus have to be reduced" (Hoekstra et al., 2011).

Some problems occur in a hotspot such as pollution or conflict and water scarcity so it can be unsustainable because of the "compromises environmental water needs" or "water quality standards", and the water use and allocation in the catchment is economically inefficient (Hoekstra et al., 2011).

This procedure should be done separately for the blue, green and grey components of water footprint of the product (Hoekstra et al., 2011).

An example of the procedure of the sustainability assessment for a hypothetical product is shown in the table 13.

Production system of this product includes six process steps. Some processes of this production system are located in different catchments (one than more) (Hoekstra et al., 2011).

As shown in the Table 13, the above-mentioned questions are asked about each component separately. Components can have a negative score on one or both criteria or it can have two positive scores. The geographic sustainability and process sustainability, which are assessed by two mentioned questions, complement each other. It means every separate component of the product water footprint can be unsustainable because of both unsustaina

bility in geographical situation (a hotspot) and an unsustainable process (Hoekstra et al., 2011).

According to Hoekstra et al. (2011) the final result of sustainability assessment of a product water footprint can be presented in term of percentage, stating "x percent of the water footprint of the product is unsustainable" (Hoekstra et al., 2011).

Table 13 **“** Example of how to assess the extent to which the water footprint of a product is sustainable, based on two criteria: geographic sustainability of the water footprints in the catchments in which the process steps are located and sustainability of the underlying process steps themselves. Priority components in the water footprint of a product can be identified based on which components are unsustainable and the share of a component in the total water footprint of the product.The table needs to be filled separately for the green, blue and grey water footprint of the product” source: (Hoekstra, 2011)

Data derived from the product water footprint account			*Check the sustainability of the total water footprint in the catchment in which the process is located*	*Check the sustainability of the water footprint of the process itself*	*Conclusion*		*Check relevance from product perspective*	*Check whether response is*
Process step[a]	*Catchment in which the process is located*[b]	*Water footprint (m^3 per unit of final product)*	*Is the catchment a hotspot?*	*Can the water footprint be reduced or avoided altogether?*	*Is this a sustainable component in the product water footprint?*	*Fraction of the product water footprint that is not sustainable*	*Share above threshold of one per cent*[c]	*Is this a priority component?*
1	A	45	no	no	yes		yes	no
	B		**yes**	**yes**	**no**	35%	yes	**yes**
2	A	35	no	no	yes		yes	no
	C		no	no	yes		yes	no
	D	10	**yes**	no	**no**	2%	yes	**yes**
	E		no	**yes**	**no**		yes	**yes**
4	F	6	**yes**	no	**no**	1.1%	no	no
	A		no	no	yes		no	no
5	A	2	no	**yes**	**no**	0.1%	no	no

[a] The production system of the product consists of a number of sequential or parallel process steps.

[b] A process step (for example, growing a particular crop which is an ingredient to the product considered) can be located in different catchments.

[c] Choosing the threshold can be subject to debate.

Besides, there are several ways for presenting the results of sustainability assessment, which is identified according to the characteristics and the aim of the project. For example experts can present the quantity of water in unsustainable use unsustainable components in total footprint or describe why identified components are not sustainable and prioritize them based on the different aspects (Hoekstra et al., 2011).

4- Water footprint response formulation (for a product)

After identifying and quantifying the green, blue and grey water footprints, reducing them and their impacts can be possible and these reduction activities are identified in this step. For example the blue water footprint can be reduced by evaporation losses minimizing from direct processes of production and closing cycles of water in the mills. Removing pollutants from the processed water can have the effect on grey water footprint and reduce it. In case of supply chain, contracts can contain some requirements related to reducing the water footprints of the suppliers, which have an indirect impact on the final water footprint of a product (Rep, 2011).

Prioritizing can be done by considering the share of a component of the certain water footprint in the total water footprint. Someone can even recommend disregarding altogether components which are not sustainable but contribute less than a specific threshold (for example one percent) of the total water footprint of the product. Besides someone can set priorities based on relative severity of the different hotspots to which the various "unsustainable water footprint components" contribute or based on which improvements can be achieved most easily and rapidly (Hoekstra et al., 2011).

Benchmarks should be developed for products. In this case someone can compare the water footprint of a product to a global benchmark of that product, which according to Hoekstra et al. (2011) can be expressed in this way, "reasonable maximum water footprint per unit of product". The final result of this assessment can be done by considering the sum of "the reasonable maximum water footprints", which have been calculated earlier for every process step of a production (Hoekstra et al., 2011).

6 Assessment

This chapter aims at assessing the four selected methods of evaluating the impacts of freshwater use in LCA: Milà i Canals et al. method (2009), Pfister et al. method (2009), Ecological Scarcity method (2006), and Water footprint method (2011). For evaluating these four methods, some criteria and sub-criteria are defined, which help to recognize advantages and drawbacks of each method, and based on the final results of this evaluation, the best method can be proposed by this project.

Selected criteria are divided in two groups:

The first group includes criteria which are drawn from different articles and guidelines related to the evaluation of water footprint methods, and mentioned as the most important characteristics for an ideal method.

1-Environmental issues addressed

2-Type of water use (Consumptive and degradative)

3-Type of water (green, blue, gray)

4-Spatial differentiation

5-Level of cause effect chain (midpoint and endpoint)

6-Area of protection

7-ISO 14044 compliance of comparative assertions disclosed to the public

8-Documentation

The second group of criteria is the one which are identified by EMInInn project for evaluating the best indicator which can be used for environmental impacts of innovation, and technological changes:

1-Relevance

2-Comprehensiveness

3-Meaning

6.1. Evaluation of the methods according to criteria group 1

Table 14. Methods and criteria group 1 (Berger and Finkbeiner, 2010a, Kounina et al., 2013, Pfister and Hellweg, 2011, JRC-IES, 2010)

Method Criterion	Milà i Canals et al. (2009)	Pfister et al. (2009)	Ecological Scarcity (2006)	Virtual Water, water foot print(2011)
Environmental issues and relevance [1] *-How many environmental issues are considered by each method?* *-Which method does consider the most environmental issues?*	Scarcity of Surface water (river, lake), groundwater (renewable, fossil), and precipitation water stored as soil moisture considered. Seawater not considered[1]	Scarcity of Surface water (river, lake), groundwater (renewable, fossil), considered. Precipitation water stored as soil moisture, and seawater not considered[1]	Scarcity of Surface water (river, lake), groundwater (renewable, fossil), considered. Precipitation water stored as soil moisture, and seawater not considered[1]	Scarcity, consumption of and contamination of Surface water (river, lake), groundwater (renewable, fossil), and precipitation water stored as soil moisture considered. Seawater not considered[1]
Type of water use (Consumptive and degradative)[2] *-How many types of water are considered by each method?* *-Which method does consider the most (both) type of water use?*	Consumptive (off-stream and in-stream)[2]	Consumptive (off-stream)[2]	Consumptive (off-stream)[2]	Consumptive (off-stream, in-stream)[2] Degradative (off-stream) (through gray water)
Type of water (green, blue, gray)[2] *-How many types of water are considered by each method?* *-Which method does consider the most types of water (all three types)?*	Blue Green[2]	Blue[2]	Blue [2]	Blue Green Gray[2]
Spatial differentiation[1] *-What spatial differentiation is made in each method?*	Spatial differentiation at watershed and country for FEI and aquifer level for FD.[1]	Spatial differentiation at the country, watershed (11050 watersheds) or 0.5° grid cell level[1]	Spatial differentiation at the country[4] and watershed level (The original method has been developed for Switzerland. Various versions of the Ecological Scarcity method have been developed for other countries or part of the world but generally it consider the water shed and national level)[3]	Spatial differentiation at the watershed, and countries where water is consumed can be distinguished at three levels (global, regional, local).[1] It can be different catchment areas such as watershed.

Level of cause effect chain (midpoint and endpoint)[2] *-How many levels of cause Effect chain are considered by each method?* *-Which levels of cause effect chain are considered by each method?*	Midpoint[2]	Midpoint Endpoint[2]	Midpoint [2]	Midpoint[2]
Area of protection[2] *-How many areas of protection are considered by each method?* *-Which areas of protection are considered by each method?*	Two indicators which cover the impact pathways: Resources (freshwater depletion(FD)) and ecosystem quality (freshwater ecosystem impact ecosystem impact (FEI))[1]	Resources, ecosystem and human health[2]	a single indicator and midpoint impact assessment method which does not cover a specific area of protection[1]	a single indicator and midpoint impact assessment method which does not cover a specific area of protection[1]
ISO 14044 compliance of comparative assertions disclosed to the public[2] *-Does each method support (consider) compliance of comparative assertions disclosed to the public?*	+[2]	+[2]	-[2]	+[2]
Documentation[4] Has the information of each method been accessible and published?	Accessible and published[1]	Accessible and published[1]	Accessible and published (Published by each country according to relevant policy targets.)[1]	Accessible and published[1]

1. Kounina et al., 2013

2. Berger and Finkbeiner, 2010

3. JRC-IES, 2011

4. Pfister and Hellweg, 2011

Each criterion is scored between one and three that will be explained in relevant part but generally grade 1 shows the worst and grade 3 shows the best method in each category.

6.1.1. Environmental issues and relevance

In this category the relevant question is "How many environmental issues are considered by each method?" or "Which method does consider the most environmental issues?". The best method is selected according to the answers of these questions so the best method is the one which considers the most environmental issues or addressed the most environmental issues.

Score 3 belongs to the best method which considers the most environmental issues, and grade 1 identifies the worst method which addressed the fewest environmental issues.

As shown in the Table 14, all methods consider scarcity of surface water (river, lake), and groundwater (renewable). Seawater is not covered by these methods. Water footprint method (2011) considers consumption and contamination, which are not considered by other three methods so the most environmental issues are addressed by this method, and the highest grade, 3, belongs to this one.

Ecological scarcity method (2006) and Pfister et al. method (2009) do not cover the precipitation water stored as soil moisture, which is considered by other two methods so the fewest environmental issues are addressed by these methods, and they are graded 1.

The grades of Milà i Canals et al. method (2009) is 2 because in comparison with Water footprint method (2011) they cover fewer environmental issues, and in comparison with Ecological scarcity method (2006) and Pfister et al. method (2009) more environmental issues are addressed by these methods.

6.1.2. Type of water use (Consumptive and degradative)

There are two types of water use, consumptive and degradative, and they are in two groups, off-stream and in-stream. The relevant question in this category is "How many types of water are considered by each method?" or "Which method does consider the most (both) types of water use?" so the best method is the one which covers both types of water use, and it is graded 3.

According to the Table 14, all four methods assess Consumptive (off-stream) but Water footprint method (2011) is the only method which also considers Degradative, and has the most complete assessment so it is the best method in this category, and it is graded 3.

Since the Pfister et al. method (2009) and Ecological Scarcity methods (2006) assess only consumptive (off-stream), their grades are 1. Although Milà i Canals et al. method (2009) only considers one type of water use, consumptive, but in comparison with Pfister et al. method (2009) and Ecological Scarcity method (2006) which only consider consumptive in off-stream water, it assesses consumptive in both off-stream and in-stream so its grade is 2.

6.1.3. Type of water (blue, green and gray)

There are three types of water (blue, green and grey), and the relevant question in this category is “How many types of water are considered by each method?” or “Which method does consider the most types of water (all three types)?” so the best method is the one which considers all three types of water, and it is graded 3.

According to the Table 14, all four methods focus on blue water and only Water footprint method (2011) considers all three types so it is graded 3. Score 1 belongs to the method which considers one type of water so the scores of Pfister et al. method (2009), and Ecological Scarcity method (2006) are 1 because they consider only blue water. Grade 2 belongs to Milà i Canals et al. method (2009) because of the consideration of two types of water, blue and green.

6.1.4. Spatial differentiation

The relevant question in this category is “What spatial differentiation is made in each method?”

According to the Table 14, watershed level is made in all methods as spatial differentiation which is a more appropriate level for an assessment because watersheds are connected to hydrological processes (Eléonore, 2010).

Spatial differentiation of Ecological Scarcity method (2006) is at watershed and country level. The original method of Ecological Scarcity had been developed for Switzerland but after years various versions of the Ecological Scarcity method have been developed for other countries but it has been develop for a few countries so in comparison with other three methods the spatial differentiation of this method is limited to these a few countries, and it is scored 1.

Spatial differentiation of Milà i Canals et al. method (2009) and Pfister et al. method (2009) are at watershed and country level, and in comparison with Ecological scarcity method (2006) , they are not limited to a few countries, so their grades are 2.

Score 3 belongs to Water footprint method (2011) because spatial differentiation of this method is at three levels, global, regional, and local so it is graded 3.

6.1.5. Level of cause effect chain (midpoint and endpoint)

There are two levels of cause effect chain, midpoint and endpoint, and the relevant question is “How many levels of cause effect chain are considered by each method?” or “Which levels of cause effect chain are considered by each method? “ so the best method is the one which considers both levels of cause effect chain, midpoint and endpoint, and it is graded 3.

Pfister et al. method (2009) proposed a method which is based on both midpoint and endpoint impacts assessment so it is the best method, and its score is 3.

Grades of Milà i Canals et al. method (2009), Water footprint method (2011), and Ecological scarcity method (2006) are 1 because they only consider the midpoint in level of cause effect chain.

6.1.6. Area of protection

There are three areas of protection: resources, ecosystem, and human health. The relevant question is “How many areas of protection are considered by each method?” or “Which areas of protection are considered by each method?” so the best method is the one which considers all three areas of protection, and it is scored 3.

According to the Table 14, Pfister et al. method (2009) covers all three areas of protection so it is graded 3. The scores of Ecological scarcity method (2006) and Water footprint method (2011), which do not cover any spatial area of protection, are 1.

Milà i Canals et al. method (2009) considers two areas of protection: resources and ecosystem. Since it covers more areas than the Pfister et al. method (2009) and Ecological Scarcity method (2006), and fewer areas than Water footprint method (2011), its score is 2.

6.1.7. ISO 14044 compliance of comparative assertions disclosed to the public

The relevant question is “Does the method support (consider) compliance to the ISO requirements for comparative assertions disclosed to the public?”

All methods except Ecological scarcity method (2006) comply with the requirements to refrain from weighting all environmental impacts into a single index.. Since the aim of Ecological Scarcity method is providing the characterization and weighting factors for different emissions and extractions according to the public policy targets, the final result of this method is fully aggregated, and it is presented in a single score which is called eco-point for supporting the LCIA calculation process.

Pfister et al. method (2009) and Milà i Canals et al. method (2009) present separate calculations and scores for different damage categories, and the Water footprint method (2011) suggests different calculations of indirect and direct water use for different type of water so the final result is presented in a separate score for each type of water.

All methods except Ecological Scarcity method (2006) can be applied in LCA studies which are intended for comparative assertions disclosed to the public, because they present a separate score for different categories and scales, and they are not fully aggregated. The Ecological Scarcity method (2006) presents only a single score as the final score after aggregation of the results of calculations, therefore the Ecological Scarcity method (2006) is scored 1 and other methods are graded 3.

6.1.8. Documentation

Since documentation and publishing, and accessibility of the relevant information of methods help stakeholders to apply these methods easier, and equip them with clear and up-to-date background knowledge about them so this criterion is very important for an ideal method. The relevant question is "Has relevant information been published in an accessible way?", and the answer is: documentation of all methods published, and accessible so the grades of all these methods are 3.

6.2. Evaluation of methods based on criteria group 1 (criteria from EMInInn project)

There are some sub-criteria are defined for each criterion in this group, which are presented in Table15

Table 15. Criteria and sub-criteria group 2

Criterion	Su-criteria
Relevance	-Importance -Responsivity
Comprehensiveness	-Environmental issues - Type of water use -Type of water -Level of cause effect change -Area of protection
Meaning	-Documentation -Transparency

6.2.1. Relevance

According to EMInInn project (2011), this criterion includes two sub-criteria, and they are defined in this way:

1 –"***Importance*****:** Each indicator should relate to an environmental aspect that policy-makers and stakeholders consider important" (EMInInn, 2011).

2-"***Responsivity*****:** The indicators and, hence, the environmental aspects should be possible to influence through innovation" (EMInInn, 2011).

According to the report "On the Progress of the Thematic Strategy on the Sustainable Use of Natural Resources", published by the European Economic and Social Committee and the Committee of the Region (2011), water footprint is one of the most important environmental issues and all industrial and social sectors have some effects on water resources, should be involved in this strategy for improving the efficiency of the implementation of this program. This program describes its aim in this way "The Communication on water scarcity and droughts in the European Union35 aims at ensuring sustainable water availability. It calls for policies to ensure that human activities do not contribute to the pressure on scarce water resources and it stresses the need to adapt economic activities to the level of water available locally. It points out how priority should be given to water savings and water efficiency measures. Only if the functioning of the water cycle is fully considered will water quantity issues be efficiently addressed" (EC, 2011a).

Besides, according to the vision of the “Roadmap to a Resource Efficient Europe” report published by the Economic and Social Committee and the Committee of the region (2011), water is one of the resources that should be managed for decreasing the environmental impacts of economic growing (EC, 2011b).

In addition water resources have been considered by the EMInnIn project as a resource affected by technological innovation.

As shown in Table 14, all these methods assess water scarcity and environmental impacts of water consumption, which are considered as the most important environmental issues, and affected by technological changes and innovation so all these methods cover both sub-criteria of this criterion, and they are graded 3.

Table 16. Sub-criteria of Relevance criterion and scores

	Milà i Canals et al. (2009)	Pfister et al. (2009)	Ecological scarcity (2006)	Virtual Water, water footprint (2011)
Importance	3	3	3	3
Responsivity	3	3	3	3
	6	6	6	6

According to Table 16, all three methods gain the highest scores, 6, so all four methods are graded 3.

6.2.2. Comprehensiveness

According to EMInInn project (2011), this criterion is defined in this way: “The set of indicators should cover the scope of relevant environmental aspects” (EMInInn, 2011).

This criterion is assessed based on three criteria presented in Table 14, which are listed below:

-Environmental issues

- Type of water use

-Type of water

-Level of cause effect change

-Area of protection

Table 17. Sub-criteria of Comprehensiveness criterion and scores

	Milà i Canals et al. (2009)	Pfister et al. (2009)	Ecological scarcity (2006)	Virtual Water, water footprint (2011)
Environmental issues addressed	2	1	1	3
Type of water use	2	1	1	3
Type of water	2	1	1	3
Level of cause effect chain(midpoint and endpoint)	1	3	1	1
Area of protection	2	3	1	1
	9	9	5	11

According to the results of this evaluation (shown in Table 17), Water footprint method (2011) has the highest grade, 11, so it is graded 3, and Pfister et al. method (2009) and Milà i Canals et al. method (2009) are scored 2. Ecological scarcity method (2006) has the lowest score, 5, so it is graded 1.

6.2.3. Meaning

According to EMInInn project (2011), this criterion is defined in this way: "The indicators and their environmental relevance should be possible to understand with reasonable background knowledge and effort" (EMInInn, 2011).

Understandable and reasonable background is necessary for describing these methods because all of these methods are new and new concepts should be described for stakeholders in the best way, and they should be equipped with proper and complete information and background about each method.

Two sub-criteria are identified for this criterion:

1-Documentation: Accessible and published

2-Transparency: Easy to understand

Table 18. Sub-criteria of Meaning criterion and scores

	Milà i Canals et ali. (2009)	Pfister et al. (2009)	Ecological Scarcity (2006)	Water footprint (2011)
Documentation	3	3	3	3
Transparency	1	1	2	3
	4	4	5	6

The results of the first sub-criteria, documentation, are based on the relevant evaluation in criteria group 1.

As show in Table 18 Water footprint method (2011) has the highest score for transparency because the relevant guideline is easy to understand and different relevant concepts, and calculation approaches are explained completely and clearly. Totally I can say In comparison with other three methods it provides the most complete and clear information for stakeholders; also the relevant concepts and calculations are made clearer by some examples. Besides, applying this method by different projects as a method for assessing water consumption, and reviewing trough many scientific journal papers, provide a rich source of information about this method for stakeholders.

There are some complete and clear guidelines for Ecological scarcity method (2006) but they are not as clear and complete as water footprint method (2011) so it is graded 2.Two other methods, Milà i Canals et al. method (2009) and Pfister et al. method (2009) have the least clear and complete information in comparison with Water footprint method (2011) and Ecological scarcity method (2006) so their scores are 1.

According to the Table 18 Water footprint method (2011) has the highest score, 6, so it is graded 3. Ecological scarcity method (2006) is graded 2, and Milà i Canals et al. method (2009) and Pfister et al. method (2009), which have the lowest scores, 4, are graded 1.

Table 19 presents the criteria group 2 and the relevant scores of each method.

Table 19. Criteria group 2 and scores

	Milà i Canals et al. (2009)	Pfister et al. (2009)	Ecological scarcity (2006)	Virtual Water, water footprint (2011)
Relevance	3	3	3	3
Comprehensiveness	2	2	1	3
Meaning	1	1	2	3

All criteria (first and second group) and their relevant scores are summarized in Table 20

Table 20. Methods and criteria group 1 and 2 and scores

	Milà i Canals et al. (2009)	Pfister et al. (2009)	Ecological scarcity (2006)	Virtual Water, water footprint (2011)
Environmental issues addressed	2	1	1	3
Type of water use (Consumptive and degradative)	2	1	1	3
Type of water (green, blue, gray)	2	1	1	3
Spatial differentiation	2	2	1	3
Level of cause effect chain(midpoint and endpoint)	1	3	1	1
Area of protection	2	3	1	1
ISO 14044 compliance of comparative assertions disclosed to the public	3	3	1	3
Documentation	3	3	3	3
Relevance	3	3	3	3
Comprehensiveness	2	2	1	3
Meaning	1	1	2	3

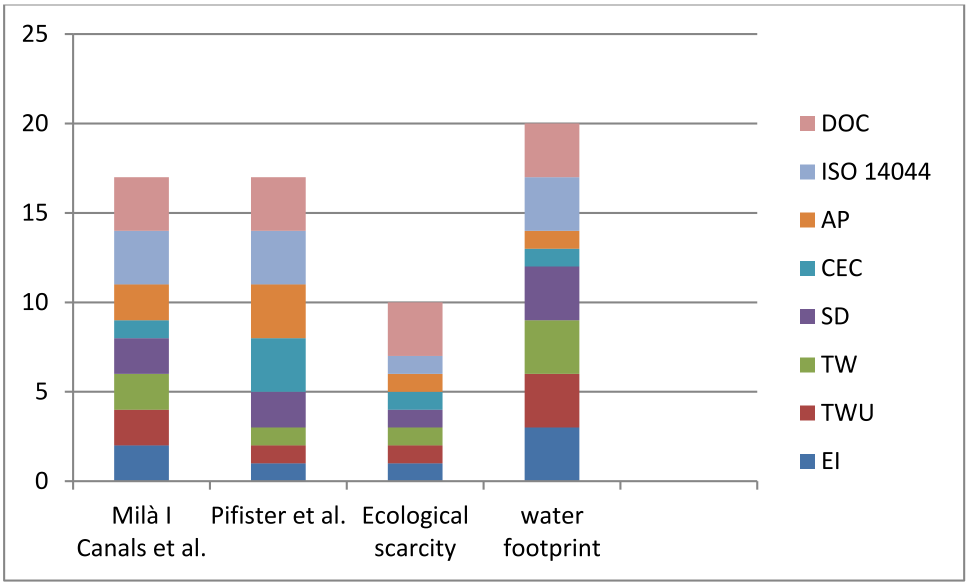

Figure 3. Mehods and criteria group 1

Figure 3 presents the results of scoring and evaluating of four methods based on the first group of identified criteria (Table 14).

Each colour shows one criteria and each column belongs to one of the four identified methods.

As shown in the figure 3, according to the results from evaluation of the criteria group 1, Water footprint method (2011) is the best method.

Table 21. Criteria group 2 and scores

	Milà I Canals et al. (2009)	Pifister et al. (2009)	Ecological scarcity (2006)	Virtual Water, water footprint (2011)
RE	3	3	3	3
COM	2	2	1	3
MEAN	1	1	2	3

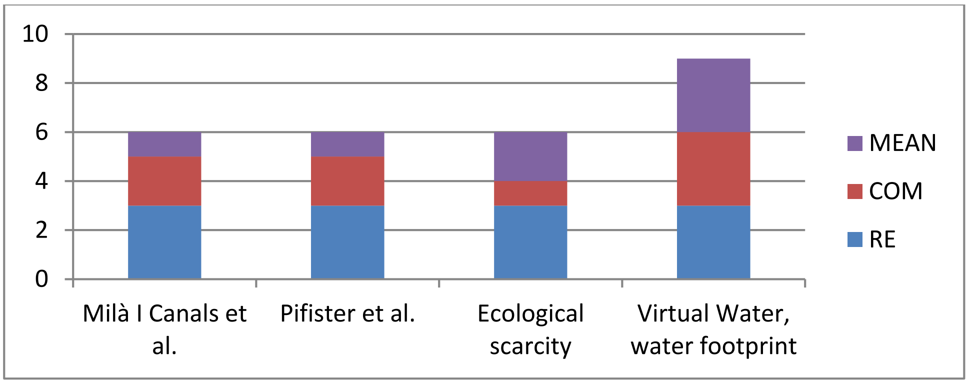

Figure 4. Methods and criteria group 2.

Figure 4 shows the results of grading four methods based on the second group of criteria.

Again in this evaluation Water footprint (2011) has the highest score and it is suggested as the best method.

Table 22. Criteria group 1 and 2 and scores

	Milà I Canals etal (2009)	Pifister et al. (2009)	Ecological scarcity (2006)	Water footprint (2011)
EI	2	1	1	3
TWU	2	1	1	3
TW	2	1	1	3
SD	1	2	1	3
CEC	1	3	1	1
AP	2	3	1	1
ISO14044	3	3	1	3
DOC	3	3	3	3
RE	3	3	3	3
COP	2	2	1	3
MEA	1	1	1	3

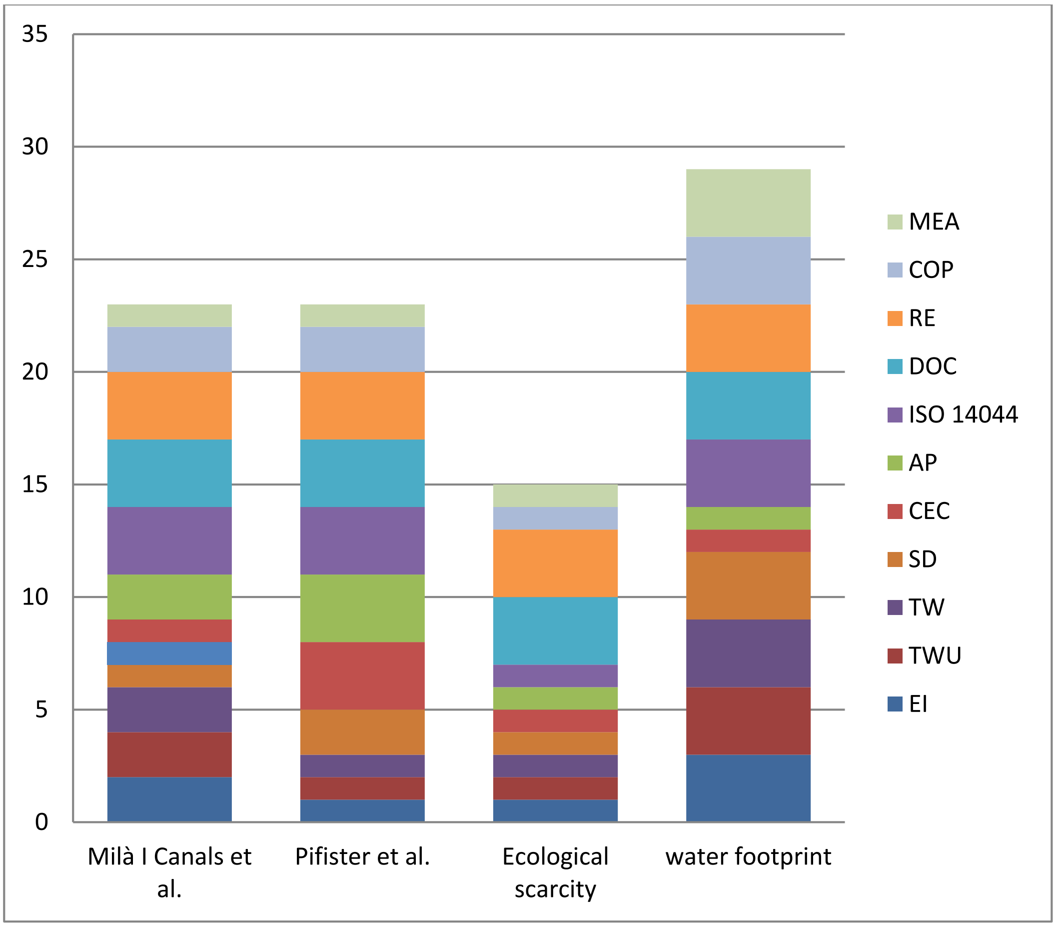

Figure 5. Methods and criteria group 1 and 2

Figure 5 summarized results from the evaluation of four identified methods based on two groups of criteria.

According to the Figure 5 which shows the final results of this evaluation, Water footprint method (2011) has the highest score, and it is proposed as the best method by this study.

7 Conclusion

This study has two aims. The first aim of this project is presenting an inventory, and assessment of existing and proposed environmental indicators for EU countries, with a focus on water use and water-related indicators. The second part aims at providing an overview of four methods of evaluating the impacts of freshwater use in LCA, and comparing them based on the selected criteria and sub-criteria, and finally proposing the best method.

According to the final results of the evaluation based on two identified groups of criteria, the Water footprint method (2011) has the highest grade, and it is recommended as the best method by this report. This method can be regarded as a comprehensive method for evaluating the water consumption in LCA, due to several criteria which are considered by this study such as a broad range of environmental (water) issues, three types of water (blue, green and gray water), two types of water use (consumptive and degradative), provides a complete and suitable background knowledge, and an easy to understand approach for stakeholders.

The last point worth mentioning at the end of this study is: the results of this evaluation are based on the implicit assumption that all criteria are equally important without any priority, but each project has its specific characteristics which identified based on its goal, and system boundaries that create some priorities for it, so since different criteria might be important in different studies, what method is the best depends on the circumstances and characteristics of the individual project.

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Appendix

Abbreviation of the counties

EEA-32 : The EEA-32 country grouping includes countries of the EU-27 (Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the Unitd Kingdom) EFTA-4 (Iceland, Liechtenstein, Switzerland and Norway) and Turkey.

EU-27: The 27 Member States of the European Union from 1 January 2007 (BE, BG, CZ, DK, DE, EE, IE, EL, ES, FR, IT, CY, LV, LT,LU, HU, MT, NL, AT, PL, PT, RO, SI, SK, FI, SE, UK)

EU-15: The 15 Member States of the European Union from 1 January 1995 to 30 April 2004 (BE, DK, DE, IE, EL, ES, FR, IT, LU, NL, AT, PT, FI, SE, UK)

EFTA: European Free Trade Association (IS, LI, NO, CH)

Candidate countries: (ME, HR, MK, TR)

BE Belgium

BG Bulgaria

CZ Czech Republic

DK Denmark

DE Germany

EE Estonia

IE Ireland

EL Greece

ES Spain

FR France

IT Italy

CY Cyprus

LV Latvia

LT Lithuania

LU Luxembourg

HU Hungary

MT Malta

NL Netherlands

AT Austria

PL Poland

PT Portugal

RO Romania

SI Slovenia

SK Slovakia

FI Finland

SE Sweden

UK United Kingdom

IS(1) Iceland

LI Liechtenstein

NO Norway

CH Switzerland

ME Montenegro

HR Croatia

MK (2):The former Yugoslav Republic of Macedonia

TR Turkey

(1) Also a candidate country.

(2) Provisional code which does not prejudge in any way the definitive nomenclature for this country, which will be agreed following the conclusion of negotiations currently taking place on this subject at the United Nations.