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EcoWater report

Review and Selection of eco-efficiency indicators to be used in the EcoWater Case Studies

IVL Swedish Environmental Research Institute

Authors: Deltares, OU, IVL
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IVL Swedish Environmental Research Institute Ltd.,
P.O Box 210 60, S-100 31 Stockholm, Sweden
Phone: +46-8-598 563 00 Fax: +46-8-598 563 90
www.ivl.se

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EcoWater ran 2011-2014. The project is presented in more detail on http://environ.chemeng.ntua.gr/ecoWater/
The project website holds a complete repository of all public deliverables from the EcoWater project.

Persons from IVL involved in EcoWater were:

Åsa Nilsson
Sara Skenhall
Magnus Klingspor
Tomas Rydberg
Uwe Fortkamp
Felipe Oliveira
Lina Danielsson
Elisabeth Hallberg

Contact person: Åsa Nilsson asa.nilsson@ivl.se

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

Collaborative project, Grant Agreement No: 282882

Deliverable 1.1

Review and selection of eco-efficiency indicators to be used in the EcoWater Case Studies

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Abstract

The purpose of Task 1.1 *Review and selection of eco-efficiency indicators according to CS specificities* is to provide an overview of different eco-efficiency indicators and suggest a process on how the Case Studies of the EcoWater Project can select the indicators that are appropriate for their specific Case Study.

This report presents an overview with insights from the literature survey and provides a list with different indicators. The literature overview focuses on the available academic and policy literature, information and knowledge on eco-efficiency indicators and assessment methodologies. We conclude that the EcoWater Eco-efficiency indicators should flexibly encompass meso-level interactions that influence the adoption and effects of micro-level changes. For this analysis, we understand the meso-level as interactions among individual technologies and different actors, resulting in interdependencies. We have researched (meso-level) indicators and parameters, and conclude that neither is "fixed" in literature. Literature does not provide a certain set of indicators applicable to eco-efficiency, let alone parameters for meso-level.

As a result, we conclude that each Case Study will use an own set of indicators and parameters. Based on a first exercise, the insights gained from literature and the different EcoWater discussions, we propose a process to cover the different aspects of the indicator and parameter selection. This process is guiding, not prescriptive - in reality the process can follow different paths.

The Case Studies can use this process to further refine their indicator and parameter identification. In this process we recommend to further the discussion on the need and means for aggregating parameters into indicators.

Contents

1 Introduction

The EcoWater Project analyses water-service systems as Case Studies in order to develop meso-level eco-efficiency indicators, as a basis to evaluate options for technological change within each system. WP1 concerns the elaboration of an analytical framework for this purpose, and within this WP, Task 1.1 focuses on eco-efficiency concepts and indicators.

The purpose of Task 1.1 *Review and selection of eco-efficiency indicators according to CS specificities* is to provide an overview of different eco-efficiency indicators and suggest a process on how the selected Case Studies in the EcoWater Project can select the appropriate indicators for their specific Case Study.

This deliverable can be seen as a first overview of available indicators. It is hence an overview document for the Case Studies to depend their future decisions with regard to meso-level eco-efficiency indicators. It also provides a step-by-step procedure for identifying indicators to assess eco-efficiency on a meso-level, rather than a fixed set of indicators.

The deliverable comprises the main document and the following annexes:

- Annex A provides main findings from literature and insight in the selection of possible indicators,
- Annex B provides an overview of parameters per indicator theme
- Annex C provides insight in all literature collected and studied.

An indicator and parameter identification template has also been developed. This spreadsheet can be made available on demand (an excerpt is presented in Figure 2), and will likely be updated during the EcoWater Project, according to the final selection of indicators in the Case Studies.

2 Methodology

As part of Task 1.1 an extended literature survey has been conducted, resulting in a literature review (Annex A) and literature overview table (Annex C). The headings in Annex A can be rephrased in the following guiding questions for Task 1.1:

- What are definitions of eco-efficiency?
- What is meso-level eco-efficiency? Why should one use meso-level?
- How does eco-efficiency relate to current (EU) policies?
- What is the relation between resource efficiency, eco-innovation and Life-Cycle Analysis?
- What are the existing frameworks for meso-level eco-efficiency?
- What are relevant indicators? What are the underlying parameters and how can one obtain indicator values from these parameters?

Literature was collected through desk study research, suggestions from partners during meetings and through advice from experts on eco-efficiency indicators and relevant literature, for example Dr. T. van Harmelen (TNO), Dr. T. Filatova (Deltares/ TU Twente) and Prof. Dr. G. Huppes (Leiden University/ CML/ EcoDrive).

Inspired on the outcome of the literature review, Deltares developed a spreadsheet to identify relevant indicators and parameters. The EcoWater Case Studies were asked to identify important indicators and parameters from this pre-developed list, and add new indicators and parameters, if necessary. The Case Study results have been brought together and function as the starting point of further refinements in the next steps of EcoWater.

At this stage, the result is a preliminary list of indicators and parameters, which will be further improved and refined.

3 The (meso-level) eco-efficiency concept

In order to understand the eco-efficiency concept, we looked at several aspects in literature; definition, policy implications, aggregation and assessment methods and decision making. On each theme, we generated a question, which is answered in this Section. The answer is a short summary of the outcomes of the literature review, hence, in the end we refer to the corresponding section of Annex A (Literature review), where more information can be found. It should be noted that the literature overview does not include national indicator schemes, since limited information was available on the topic of eco-efficiency with regard to national schemes and, hence, it was impossible to draw implications on this matter.

3.1 Definition

Eco-efficiency generally refers to a relationship between socio-economic benefits (or societal welfare) and environmental impacts (or burdens) of the same activities, as a basis for improving that relationship. Often this relationship is expressed as a ratio of economic vs. environmental parameters, whereby the two components could be calculated for making comparisons of options or strategies. It is important to consider change (over time), as today's eco-efficiency may be quite different tomorrow, as a result of changing economic and environmental parameters. However, different equations are used. Table 1 shows different equations from literature and links to other concepts.

Table 1: Eco-efficiency is…

Definition	Source
$\frac{Economy}{Resources}$	Mol and Gee, 1999, also referred to as resource productivity
$\frac{Environmental\ Impact}{Unit\ of\ Product}$	Huppes & Ishikawa, 2007 and 2009, also referred to as environmental productivity [i.e. the reverse of eco-efficiency]
$\frac{Environmental\ Performance}{Financial\ Performance}$	Muller et al., 2001
$\frac{Economic\ Value\ added}{Environmental\ Impact\ added}$	WCED, 1987, cited in Mickwitz et al., 2006
$\frac{Value\ added + Intermediate\ Consumption}{Environmental\ Impact}$	Seppala et al., 2005

As a concept for redesigning production systems, however, eco-efficiency generally has meanings broader than a ratio to be calculated. They can be listed from the broadest to the narrower:

- An activity, continuous process and/or philosophy for improving the relationship between welfare and environment (especially according to earlier accounts, e.g. Schmidheiny, 1992; OECD, 1998; WBCSD, 2000; WBCSD, 2006, see below; Taylor et al., 2006);

- Specific added benefits and/or reduced environmental impact from process changes (e.g. WCED, 1987);
- A quantifiable ratio as a baseline and/or as a change (e.g. Seppala et al., 2005).

See in Literature review: Annex A, § 1.3

3.2 EU and policy implications

The "eco-efficiency" concept originated in 1990s debates about pathways and choices for sustainable development. As a policy concept, eco-efficiency has been linked with resource efficiency in various ways, especially for decoupling economic growth from resource usage and pollution, as a means towards sustainable development. It was generally related to as follows:

eco-efficiency strategies → resource efficiency → decoupling = sustainable development

At issue was whether environmental improvement contradicts economic advantage, and thus inherently requires trade-offs, or rather complements economic advantage as an incentive and benefit of appropriate systems design. To promote the latter perspective, the eco-efficiency concept links several aspects – resource efficiency, systems' redesign, techno-scientific advance, stakeholder cooperation, policy incentives and the broad knowledge necessary to promote improvements.

However, different EU policy bodies and programmes (CEC, EEA, the 5th Environmental Action Programme) have also linked eco-efficiency with wider aims of sustainable development. In this policy evolution, the questions raised include, amongst others, the following:

- How can we identify eco-efficient improvements (especially by mimicking nature)?
- How can we identify opportunities and remove barriers for implementation of eco-efficiency measures?
- How can we evaluate their overall environmental effects?

In recent years the eco-efficiency concept has been nearly displaced by resource efficiency. As a result, eco-efficiency is narrowly relegated to an adjective, describing presumed characteristics of innovative technologies or products (as it were a built-in characteristic, e.g.: eco-efficient technologies or products). The above described link to resource efficiency results in a focus towards decoupling economic growth from resource usage. This aim has also been called de-materialising the economy, e.g. by reducing material inputs and/or substituting renewable materials for non-renewable ones.

A suggestion is that in order to maximize policy relevance, the study of eco-efficiency needs a clear conceptual link to resource efficiency and decoupling.

See in Literature Review: Annex A, §1.1.1 and §1.1.2

3.3 Relationship to Life-Cycle Analysis (LCA)

Life Cycle Analysis (LCA) is a concept and tool for assessing the environmental impact of a product or service during its lifetime; it is also known as the "cradle to grave" approach. The basis of the LCA concept is an energy and material balance over the system that provides the specific function of a service or product, linking all inputs and outputs to their ultimate origin or fate in natural resources.

Eco-efficiency is a way to correlate environmental impacts with economic value in business or society. This is a difference from LCA, which considers only environmental impacts, and not economic costs or values. The definition of eco-efficiency does not imply how to determine the environmental impact (nor how to determine the value), but it seems reasonable to use the same object of study for both the value and the impact.

To track every flow associated with a product or service's life cycle, LCA is very demanding of data collection and quality, so usually a cut-off point sets a boundary for practical reasons. The methods to identify system boundaries and cut-of points may be useful in decomposing the EcoWater case studies.

LCA is well applicable for meso-level objects of study. Thus, LCA can be a useful underlying tool for the environmental aspects when working with meso-level eco-efficiency to ensure inclusion of all relevant emissions along the value chain.

3.4 Meso-level eco-efficiency

The EcoWater project focuses on water-service systems, as a basis to identify the meso-level for relevant eco-efficiency indicators. Each water system may overlap with various inputs, sectors and products, together comprising the meso-level. In the literature review the following questions were guiding: Why should one study eco-efficiency at a scale intermediate between the micro and macro? How can we identify the meso-level? Two answers to this are:

- Socio-technical dynamics of innovation: Drivers for eco-efficiency measures, and likewise interactions that influence their adoption, cannot be readily identified at the micro or macro level alone.
- Interactive environmental effects: Macro-level eco-efficiency gains do not simply add up micro-level improvements – e.g., because the latter may be undermined elsewhere in the supply chain and/or because such improvements may depend on intermediate-level interactions.

However, the eco-efficiency literature does not clearly characterize a meso-level scale as qualitatively different than a macro-level scale; nor does the literature identify relevant boundaries. For the meso-level scale, the unit of analysis can be a system, a process, a product, etc. Some literature implicitly assumes that the meso-level scale is an intermediate-level production volume, geography, etc. Within EcoWater it is natural that the agriculture and urban cases are focused around a geographical region (in other words the local to regional water system), while in the industry cases the boundaries could be described in another way (e.g. sector). However, in agriculture, too, geographic boundaries may sometimes be less easy to use, as also water for agriculture may be transferred from other regions.

There is not a lot of literature specifically focusing on the meso-level, but Schenk et al. (2007) give a good workable definition about identifying the meso-level in a value chain: The meso-level can be defined by interactions among individual technologies and different actors, resulting in interdependencies.

From Schenk (2007), key characteristics of the meso-level system are interdependent dynamics among heterogeneous actors:

- Coupling of individual technologies and groups of actors, resulting in interdependencies and interaction
- Focus on dynamic behaviour of interdependencies of individual system elements.

Such a meso-level analysis can provide additional information on systems' responses to change and insight for long-term planning. Thus, the meso-level interactions are more complex than an intermediate scale between the micro and macro levels.

See in Literature Review: Annex A, § 1.1.6

3.5 Decision making

According to various literature sources, eco-efficiency indicators are meant for several kinds of decision-making and makers (*See in Literature review Annex A: § 1.1.7)*:

- Comparing alternative options to improve a system;
- Allocating resources to foster the uptake of specific options;
- Designing policies (e.g. fiscal, regulatory, R&D, green procurement) which can promote or stimulate improvements; and
- Communicating such judgments to wider audiences, e.g. policy-makers, industry, investors, consumers, etc.
- Stimulating Corporate Social Responsibility, mostly applicable to multi-national companies, which in themselves can operate (in terms of scope) at meso-scale. Eco-efficiency can be a driver in terms of corporate responsibility to become more sustainable.

The aforementioned decisions mainly concern micro- or macro-level decisions, e.g. for a factory or for a specific policy development. Similar to the previous Chapter, Meso-level eco-efficiency, information on meso-level eco-efficiency decisions is rare. On the other hand, a key EcoWater result concerns: *"A validated and tested methodological framework for assessing technology impacts on the eco-efficiency of water service systems"*, where water service systems are considered as meso-level systems. This implies that there is a group of stakeholders and actors within EcoWater's Case Studies who make decisions leading to enhanced eco-efficiency. It is useful to look at their interrelations, because these can enable better decisions. The meso-level will provide insight in which changes in the value chain (other technologies, extensions) will have the highest chances of a successful improvement on eco-efficiency, as the system and system dynamics are analyzed. This means that for example a solution at micro-level which focuses on households (e.g. replacement of showerheads), can be an eco-efficient option at the micro-scale, but when relating it to the system, it can be even more eco-efficient to e.g. prevent leakage in the distribution network. 'Individual economic actions are not created in a void but are intricately related. Reducing emissions at one spot may well lead to more than compensating increases in other spots' (Huppes and Ishikawa, 2007, 2).

Following on this aspect of interrelations, and after Schenk (2007), the essential aspect in meso-level eco-efficiency is interrelations and interaction, also distinguishing between meso-level eco-efficiency decisions and micro-level decisions. This means that when looking at eco-efficiency, we need to consider different kinds of decision makers (actors/ stakeholders/politicians) and the type of decisions (technology, collaboration/ social benefits[1]) that they can make. Joint responsibility over a meso-level system may lead to other decisions and hence eco-efficiency gains, compared to independent decisions focusing on specific stages of the water service system.

Inspired by the EcoWater case studies, we believe the following decisions/discussions would require a meso-level assessment for options towards eco-efficiency enhancement. The examples are not case-based and should be considered as an inspiration for the type of decision making at the meso-level scale.

- Agriculture / regional government: The regional water authority wishes to decide if it should invest to increase water supply or to decrease water demand. What is the eco-efficiency of different strategies – e.g. increased groundwater extraction, water transfer from other basins, desalination, changing crops, water pricing, or training on water management – compared to 'business as usual' (BAU)? How do different options have different costs and benefits for different stakeholders? Who benefits from the different strategies, and who would bear the costs? What can be done to mitigate such inequities in benefits and costs? How can the regional water authority guide discussions leading to a widely supported decision? What are the long-term implications, e.g. how much climate-proof are the proposed solutions? A meso-level analysis should support this type of decision making process.
- Agriculture / individual farmers: Local farmers would like to increase their joint income without increasing (or even by reducing) environmental impact. They assume an increase in water prices in the coming years. In BAU, some farmers benefit more than others from public investments in irrigation systems. A collective decision needs to be made about water distribution, phased investments in advanced irrigation, etc. This requires an eco-efficiency analysis that is similar to an optimization study.
- Agriculture / drinking water / tourism: The water utility foresees that it may need to invest in additional purification steps in the local drinking water treatment plant. To avoid this investment, the company needs to assess if it is feasible to improve raw water quality. One option is to negotiate with

[1] Eco-efficiency metrics (vs. sustainability metrics) concern economic and environmental aspects. Social aspects are not included in eco-efficiency metrics per se (but can be indirectly addressed).

upstream ‘polluters’, for example upstream industry or agriculture. To develop such options, a meso-level analysis will provide the basis to weight up different options. In this case study, additional economic value could be achieved by including ‘recreation’, as a better overall surface water quality may result in more leisure activities.

In summary, and for each case of systemic change, a meso-level analysis should compare the relative eco-efficiency of different options, and particularly the effects on diverse stakeholder-dependent economic and environmental parameters.

See in Literature Review: Annex A, § 1.7

4 Indices, indicators and parameters

The purpose of Task 1.1 *Review and selection of eco-efficiency indicators according to CS specificities* was to provide an overview of different eco-efficiency indicators and suggest a process on how the Case Studies in the EcoWater project can select appropriate indicators for their specific Case Study.

We define an indicator as a numerical value representing an issue such as 'climate change'. Such a numerical value is typically based on parameters for different quantities, e.g. a combination of the values of CO_2. and CH_4, both considered important drivers for climate change. It goes without saying that any aggregation involves cognitive and normative judgments. The process normalizes (standardizes) various parameters for their comparability and assigns relative weights, necessarily dependent on subjective values. Such aggregation can provide a more transparent means to deal with environmental impact indicators, as a basis to facilitate decision-making and policy support. However, this process also results in the loss of information that can be important for several aims – e.g. differentiating among effects, for choosing among options, and for engaging stakeholders in a specific or wider environmental context. In conclusion, when developing and handling indicators and parameters, care must be taken to avoid being misled by the selection of underlying parameters and means of aggregation.

We define an index or indices as an aggregate of indicators, in other words an aggregation of aggregates. Here it becomes even more obvious that aggregates require subjective weighting: How to combine a value for Climate Change with a value for 'Acidification'?

In summary:

- Parameters are usually observed data (e.g. oxygen concentration), possibly standardized to a certain scale (e.g. oxygen saturation);
- Indicators are aggregates of parameters, usually around a specific (societal or environmental) theme;
- Indices are aggregated indicators.

Frame 1 provides an overview/illustration of the issues concerning aggregation.

With regards to indicators, the headers of indicators sometimes reflect more the 'societal concern' like 'climate change', or a more process based approach according to input/output of a system and groups of 'emissions'. These headers are strongly correlated, meaning that the input/output based 'emission of acidifying compounds to air', is quite equivalent to a societal theme of 'dying forests (due to acidification)'.

Table 2 provides an overview of indicators based on the literature review. The societal themes are grouped around 'Input', 'Output', 'Both' and none:

Input: An indicator in this category indicates that the environmental impact (of the underlying parameters) is associated with the resources needed within the water service system (i.e. with the input of raw materials).

Output: An indicator in this category indicates that the water service systems emissions (solid, gaseous, liquid) exert pressure on the environment.

Both: 'Both' implies that the water service system has a negative impact on both inputs and outputs.

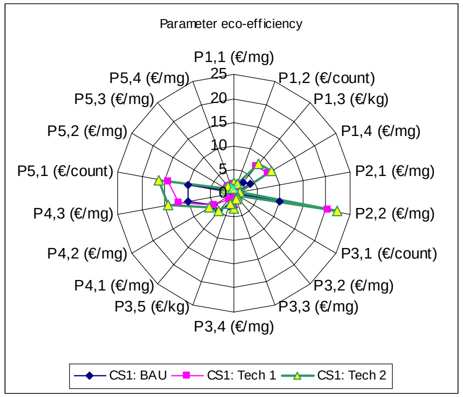
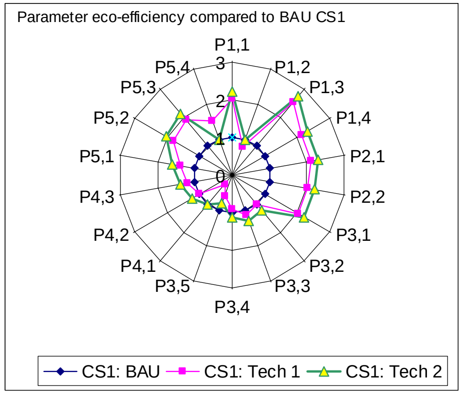
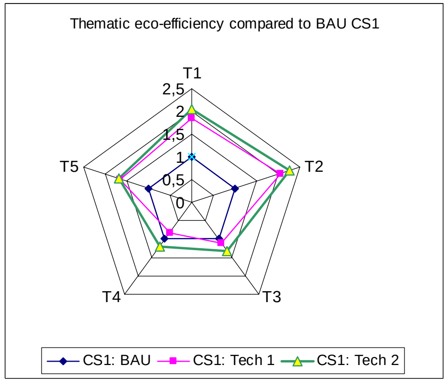
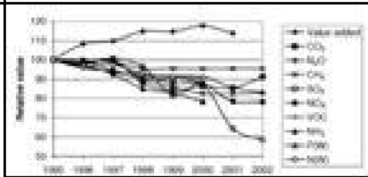
Table 2: Indicators (values in brackets indicate the number of identified parameters - see Annex B)

Input		**Output**		**Both**	
Resource availability / (Input) Resources	(21)	Climate Change & Global warming	(9)	Water availability	(13)
		Receiving Water Quality	(21)	Biodiversity	(3)
		Acidification (emissions to air)	(4)	Ecosystem health	(11)
		Ozone depletion	(6)	Soil health and productivity	(1*)
		Health / Air Quality	(8)		
		Waste	(8)		

(*) Soil health and productivity is included in this overview after the stakeholder consultation for the Monte Novo Case Study in Portugal, April 2012. This indicator theme has not been yet investigated, but was acknowledged to be of importance for the agricultural case studies and hence, parameters should be developed for this indicator theme. Stakeholder consultation shows that at this stage it is still impossible to select a final and definite set of indicators, as insight from local experts and stakeholders is needed.

See in Literature Review: Annex A, § 1.4 and Annex B

Frame 1: Description and reflection on different levels of aggregation

Level of aggregation **Issue**	**Parameter level Raw data**	**Parameter level normalized**	**Indicator theme (collective criteria*)**	**Eco-efficiency index**
Description	Original, observed values	Original values, but normalized	Rough figures, normalization needed	One value
Visual example 1				
Visual example 2				
Advantage	All information is retained for decision making	Detailed figures, but many data.	Strategic level (scope and vision) Different case studies can use different parameters, based on relevance and availability.	Lacks detail
Disadvantage	Very complex for decision making. Difficult scaling due to different units.	Still quite complex for decision making. Critical to the method of normalization.	Quite many aggregations required. Critical to the method of normalization.	Many weightings and scalings (normalisation)

Source tables: Seppala et al., 2005

*** More info in UNEP, 2008**

5 Indicator selection

For meso-level analysis, indicators need to be relevant to the entire system. They should also show whether eco-efficiency improves or declines and in which respect. This is not synonymous to system-wide, meaning that an indicator does not need to be relevant to each “stage” or “node” of the system. The term “node” is used here to denote for example “Intake of Water”, “Irrigation channel”, “Reservoir”. Together, the nodes form the water service system, as depicted in Figure 1.

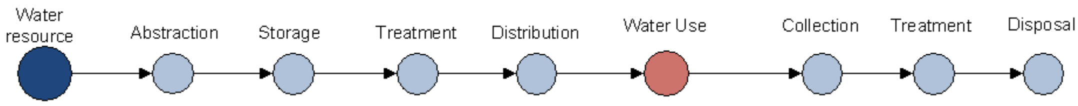


Figure 1: Example high level decomposition of a water services system into nodes

However, what criteria can be used to select the appropriate indicators? We can suggest the following general criteria from the literature:

- Relevance for the different stakeholders, including support to management decisions and actions/ sufficient communication capability to be used.
- Data availability at the appropriate scale and in consistent (standard) units (e.g. kg, m^3, EUR).
- Sensitivity to change over time and to alternative future scenarios.

However, we do not only want to select indicators, we also want that these indicators are able to measure impacts at the meso-level. This implies that it is necessary to describe Business-As-Usual (BAU) practices, to serve as the baseline for anticipated or planned improvements and their meso-level effects. A distinction can be made between absolute improvement (decoupling) vs. relative improvement (BAU).

At this, early stage, of Case Study development, the EcoWater Case Study Leaders were asked to identify potential indicators and parameters for each “node”. The actions required were:

- Assess the importance of the different indicators to the Case Study, through expert judgment
- Describe per node the parameters that are most important.

Figure 2 provides an excerpt from an intermediate result.

			Node			
						Water Supply
Case Study	Monte Novo		Alqueva	Conveyance canal/duct I	Loureiro Reservoir	Conveyance ca
Name	<-name		1	2	3	4
	Node name ->					
Indicator	**Parameter**	Units				
Climate Change/ global warming	CO2 to air emission	t/year	Important	Important	Not imp.	Not im
	CH4	t/year	Not imp.	Not imp.	Not imp.	Not im
	CFC	t/year	Not imp.	Not imp.	Not imp.	Not im
	N2O	t/year	Not imp.	Not imp.	Not imp.	Not im
	Chloride	t/year	Not imp.	Not imp.	Not imp.	Not im
Water quality (this may be split into	NO3	g/L	Not imp.	Not imp.	Not imp.	Not im
	NH4	g/L	Not imp.	Not imp.	Not imp.	Not im
	N Total	g/L	Not imp.	Not imp.	Not imp.	Not im
	PO4	g/L	Not imp.	Not imp.	Not imp.	Not im
	P Total	g/L	Not imp.	Not imp.	Not imp.	Not im
	BOD (Biological oxygen demand)	g/L	Important	Not imp.	Important	Not im
	COD (Chemical oxygen demand)	g/L	Important	Not imp.	Important	Not im
	Total Pesticides and Fertilizers	g/L	Not imp.	Not imp.	Not imp.	Not im
	TSS (Total Suspended Solids)	g/L	Not imp.	Not imp.	Not imp.	Importa
	pH		Not imp.	Not imp.	Not imp.	Not im
	SAR (Sodium Adsortion Ratio)		Not imp.	Not imp.	Not imp.	Not im
	Microorganisms (e.g coliform)		Important	Not imp.	Important	Not im
Water Quantity	Total volume per year/ per season	m3/year	Important	Important	Important	Importa
	Abstracted water	m3/year	Important	Not imp.	Important	Not im
	Used water per ha	m3/year	Not imp.	Not imp.	Not imp.	Not im
	Leakages	m3/year	Not imp.	Important	Not imp.	Importa
	Evaporation/Evapotranspiration	m3/year	Important	Not imp.	Important	Not im
Acidification (emissions to air)	SO2	t/year	Not imp.	Not imp.	Not imp.	Not im
	NOx	t/year	Not imp.	Not imp.	Not imp.	Not im
	HCl	t/year	Not imp.	Not imp.	Not imp.	Not im
	NH3	t/year	Not imp.	Not imp.	Not imp.	Not im
		t/year				
Tropospheric ozone formation / d	NOx	t/year	Not imp.	Not imp.	Not imp.	Not im
	NMVOC (nonmethane volatile organic compounds)	t/year	Not imp.	Not imp.	Not imp.	Not im
	CO	t/year	Not imp.	Not imp.	Not imp.	Not im
	CH4	t/year	Not imp.	Not imp.	Not imp.	Not im

Figure 2: Example of parameter and indicator identification per node

Table 3 presents the results of the indicator selection exercise. Not surprisingly, the key themes (indicators) are the receiving water quality, water availability and resource availability. Climate change and waste are frequently considered (possibly) important.

Table 3: Results of the indicator selection exercise in the EcoWater Case Studies

Indicator theme	**Agriculture**		**Urban**		**Industry**			
	Sinistra Ofanto	**Monte Novo**	**Zurich**	**Sofia**	**Textile**	**Energy**	**Dairy**	**Auto-motive**
Climate Change & Global Warming	1	1	1	2	1	1	1	0
Receiving Water Quality	2	2	1	2	2	2	2	2
Water availability	2	2	2	2	2	2	1	1
Acidification (emissions to air)	0	1	0	0	0	0	0	0
Ozone depletion	0	1	0	1	0	0	0	0
Ecosystem health	0	0	1	1	2	0	0	1
Biodiversity	1	0	0	1	1	2	0	0
Health/air quality	1	1	0	0	0	0	1	0
Resource availability	2	2	2	2	2	2	2	2
Waste	1	1	1	2	2	0	0	2
Legend: 0= not important; 1 (blue) = possibly important, 2 (pink) = important								

Furthermore, we also asked for an assessment of the importance of certain parameters per node in the value chain (an overview of potential parameters per indicator theme is provided in Annex B). However, Case Study leaders have filled this template with their own assumptions; thus, there are some cases where almost all nodes are considered important with regard to the impact of a certain parameter, and other Case Study where only one or two nodes have been identified as important to. It should first be investigated how the template can be improved to draw conclusions on that level.

From the Case Study's selection of parameters we generated in total a list of over 100 relevant parameters (Annex B). This does not imply that all Case Studies need to include all parameters. On the contrary, a Case Study should select those parameters most relevant to meso-level eco-efficiency effects of systemic-technology changes.

6 Recommendations

The EcoWater eco-efficiency indicators should flexibly encompass meso-level interactions which influence the adoption and effects of micro-level changes. We have researched (meso-level) indicators and parameters, and conclude that neither is "fixed" in the pertinent literature. Furthermore, the literature does not provide a certain set of indicators applicable to eco-efficiency, let alone parameters for the meso-level. As Huppes said during an interview, “there are no authoritative frameworks”.From this perspective, we can conclude that each Case Study will use an own set of indicators, derived from a common base. Based on this first exercise, insights gained from literature review, and ongoing discussions in EcoWater, we propose a process to cover the different aspects of the indicator and parameter selection (Table 4). This process is guiding, not prescriptive.

Table 4: A guiding process for indicator and parameter selection

Step	Action
0	**Identification of relevant stakeholders and fostering of their involvement in all subsequent steps**, based on what do we already know or need to know from the interaction of the stakeholders and actors in the chain?
1	**Decomposition of the water service system in “nodes”and re-assessment of the stakeholder analysis.**
2	**2a Assessment of the relevance of indicators for each node of the system:** As the indicators are based on issues considered environmentally, economically or socially significant, one can start by narrowing down the indicators based on their relevance within the region of the water service system. **2b Combination of the results to select a number of priority indicators for the Case Study:** It is important to assess whether the group of stakeholders are the problem owner. A strive towards increasing the overall eco-efficiency of a water service system would benefit from clear ownership of ‘problems’.
3	**Development of a list of potential options for eco-efficiency improvements**, by assessing, for each option, the following: (a) Whether the relevant stakeholders are included in the process (if not, it is unlikely that the option will be implemented, and thus, there is need to return to Step 0) (b) Which parameters at which node the option is likely influencing, considering the “nodes” at hand.
4	**Assessment of whether the options influence parameters that correspond to the indicators selected in Step 2**: If there is a poor matching between options and their parameters on one hand, and indicators on the other hand, a re-development of step 3 is the most obvious step, resulting in more appropriate options. If there is a good match, then proceed to Step 5.
5	**Identification of whether the selected parameters are already measured / monitored (over time)**: If parameters are not yet measured, then assess if (a) they can be measured and/or (b) there are other parameters measured which are as informative. If there is no means of monitoring a parameter or finding an alternative parameter, the stakeholders should decide if the option remains relevant (Step 3).
6	**Development and review of a final list of indicators and parameters**
7	**Selection of methods for data normalization and aggregation**: The indicators are aggregations of one or more parameters. Parameters can be measured at a certain node in the value chain. The indicator is generated through the interaction of different parameters, hence the meso-level is described through the data from different nodes in the chain. However, the method used to aggregate parameters into thematic values needs further elaboration. At this stage, the method for aggregation has not been yet selected. It should be noted that, while it is not very likely, the method of normalization may require a reassessment of parameters.

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For the full list of references, please refer to Annex A, Section 3.

Description of Work", EcoWater, Grant agreement no:282882.

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

Collaborative project, Grant Agreement No: 282882

ANNEXES to Deliverable 1.1

Review and selection of Eco-Efficiency indicators to be used in the EcoWater Case Studies

April 26th, 2012

DOCUMENT INFORMATION

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Contents

Annex A Literature Review

The literature review addresses numerous issues. Each section starts with a question continues with a summary answer and follows with a more detailed elaboration. The contents table of Page 3 can help you navigate to the sections of interest.

A.1 Eco-efficiency: policy, analytical and methodological issues

This Chapter analyses how eco-efficiency is related to concepts, such as resource efficiency, decoupling, sustainable development, eco-innovation, etc. The literature review identifies gaps and weaknesses that should be addressed by further research.

A.1.1 Eco-efficiency: linking EU policy with research agendas

Question: How does the eco-efficiency concept link policy with research?

Summary answer: The EU policy has linked eco-efficiency with wider aims of sustainable development. This has been often specified as resource efficiency, towards decoupling economic growth from resource usage. This aim has also been called de-materialising the economy, e.g. by reducing material inputs and/or substituting renewable materials for non-renewable ones. Policy documents have placed varying emphasis on business and/or government actors who have knowledge-needs and responsibilities for measures to achieve resource efficiency. Research is meant to clarify means, opportunities, incentives, barriers and indicators of eco-efficiency measures, especially their contribution to the wider aims of resource efficiency and decoupling.

EU policy: eco-efficiency of/for what?

Question: How does eco-efficiency relate to EU policies?

Summary answer: The concept originated in 1990s debates about pathways and choices for sustainable development. At issue was whether environmental improvement contradicts economic advantage, and thus inherently requires trade-offs, or rather complements economic advantage as an incentive and benefit of appropriate systems design. To promote the latter perspective, the eco-efficiency concept links several aspects – resource efficiency, systems redesign, technoscientific advance, stakeholder cooperation, policy incentives and the broad knowledge necessary to promote improvements. In recent years, the eco-efficiency concept has been largely reduced to an adjective, e.g. eco-efficient technology or products, as if it were a built-in characteristic of a thing. There are similarities between the meanings of eco-efficient technology, eco-innovation and environmental technology, though the latter may neglect economic aspects.

As a policy concept, eco-efficiency originated in the 1990s. Then, the 5th Environmental Action Programme aimed:

> to develop and give practical form to policies aimed at sustainable industrial development, involving the formulation of the concept of eco-efficiency, and partnerships between governments and industry, using industry's capacity for innovation and appropriate incentives and stimulating conditions, on both the demand and the supply side (CEC, 1998: 5).

Likewise its successor (the 6th Environmental Action Programme) emphasised the need to do more with less:

> Objective: to ensure the consumption of renewable and non-renewable resources does not exceed the carrying capacity of the environment. To achieve a de-coupling of resource use from economic growth through significantly improved resource efficiency, dematerialisation of the economy, and waste prevention (CEC, 2001a: 4).
>
> Business must operate in a more ecoefficient way, in other words producing the same or more products with less inputs and less waste, and consumption patterns have to be more sustainable (CEC, 2001b: 3).

Around that time, a similar link to government action was emphasised by the European Environment Agency (EEA):

> Eco-efficiency is the concept that allows us to create the type of information that governments need to help integrate environmental objectives into economic policies in order to achieve de-coupling of the use of nature from economic growth, thereby contributing to more sustainable development (Domingo Jiménez-Beltrán, Executive Director of EEA, quoted in WBCSD, 2000: 23).

Such statements incorporated concepts from industry: given the increase in resource usage, it is possible to decouple these trends 'so that the economy and quality of life continue to rise while resource use and pollution fall away' (WBCSD, 2000: 23).

Although eco-efficiency can refer to a sector or entire economy, policy statements have often attributed eco-efficiency to specific process or product (technology). According to the EU's Environmental Technologies Action Plan (ETAP):

> The more widespread application of existing processes, techniques and products, and future technological breakthroughs will allow economic growth to be decoupled from environmental impacts, thereby reconciling economic and environmental objectives. Many companies in Europe and elsewhere have already realised that moving to more eco-efficient production and products will both improve environmental performance and cut costs for energy, resource input and waste management (CEC, 2004: 6).

The ETAP identified major obstacles to eco-efficiency:

> Many potentially significant environmental technologies exist, but are underused. Many factors contribute to this. These include the lock-in to existing technologies, price signals that favour less eco-efficient solutions, difficult access to finance and low consumer and purchaser awareness. This situation needs to be significantly improved for environmental technologies to prosper (ibid: 7).

'Absolute decoupling' via eco-innovation has been emphasised by the European Commissioner for Environment:

> Moving towards becoming a resource efficient society is no longer a choice. It is inevitable; it is only a question of time… The resource efficiency agenda for me is about 'real or absolute decoupling'. It is about reducing overall resource use and the impacts of that resource use from economic activities, to sustainable levels. It is about implementing the aspiration of sustainable development... we

> should also actively support eco-innovation and eco-design through public policy (Potočnik, 2011).

Eco-innovations are also known as environmental technologies.

Some academic approaches have been criticised for not generating relevant knowledge for an eco-efficient economy – e.g., by failing to identify opportunities and blockages, or even by impeding the necessary knowledge. DG Environment has criticised analytical blockages:

> We can see many blocks which could prevent us from reaching an eco-efficient economy – and some of those are analytical. Some of those analytical blocks are from an absence of research into particular areas, and so a lack of information. Some of those blocks are from inertia in schools of thought – particularly economics – that shape political and economic discourse even when they are not providing the guidance that we need. The view I have from the Commission is that, if we are to be successful in creating the policy for eco-efficiency, we need your help to remove both forms of blocks (Hudson, 2010).

Originating in 1990s environmental policy, the eco-efficiency concept has been extended to wider policy areas, e.g. innovation and trade. Policy language often reduces eco-efficiency to quasi-human powers of specific technologies. The Commission seeks 'increased industrial competitiveness through innovative eco-efficient bio-based products' (CEC, 2009: 9). Trade policy promotes…

> innovative ideas and new market opportunities for eco-efficient technologies, processes and services contributing to decreasing material inputs, increasing resource productivity, minimising waste and recycling waste as a resource of secondary raw materials, which will offer new opportunities for SMEs (CEC, 2011c).

FP7 rationale: socio-technical dynamics of eco-efficiency

Question: How do EU research agendas conceptualise eco-efficiency and its policy role?

Summary answer: Within the 7th Framework Programme, research agendas encompass diverse accounts of eco-efficiency (similar to those surveyed above). In the Food, Agriculture, Fisheries and Biotechnology (FAFB) programme, for example, the concept is narrowly relegated to an adjective, describing presumed characteristics of innovative technologies or products; from this perspective, policy has the main task to facilitate such innovations. In the Environment programme the concept has broader, contingent meanings. In particular, 'the socio-technical dynamics' include several aspects – how to identify systemic improvements beyond changes in specific inputs, how to identify eco-efficient improvements (especially by mimicking nature), how to identify opportunities and barriers for implementation, and how to evaluate their overall environmental effects at a larger scale. From this perspective, policy could make better judgments about selectively promoting eco-innovations and ensuring their environmental benefits.

DG Research has elaborated concepts and research agendas for eco-efficiency, alongside assumptions about its policy role. Diverse perspectives appear across different thematic areas of Framework Programme 7, as surveyed in this sub-section.

In the Food, Agriculture, Fisheries and Biotechnology (FAFB) programme, a Knowledge-Based Bio-Economy is defined as 'the sustainable, eco-efficient transformation of renewable biological resources into health, food, energy and other industrial products'. Beneficial characteristics are attributed to such products: 'Eco-efficient products are less polluting and less resource-intensive in production, and allow a more effective management of biological resources' (DG Research/FAFB, 2006: 3). The agro-food section mentions 'high-tech, eco-efficient processing and packaging systems, smart control applications and more efficient valorisation and management of by-products, wastes, water and energy' (DG Research/FAFB, 2011).

In the DG Research 'Environment' programme, by contrast, the eco-efficiency concept plays several broader roles, e.g. as an aim of eco-innovation, as a 'natural' model for benign innovations, and an indicator to monitor progress towards resource efficiency. In the 2011 work programme, the first objective is 'to provide integrated solutions for action on adaptation to and mitigation of climate change'.

> The second objective is, through research, to support eco-innovation for eco-efficiency in society. The transformation to sustainable societies implies the development and availability of technologies, products and services that help to minimise the environmental "footprint" of all human activities through energy and resource efficiency. Research will promote cutting-edge technologies and management options, facilitating the emergence of world-class clusters for competitiveness, while examining the complex interplay between social and technological change. In WP2011, particular attention is given to a new generation of technologies which, designed through methodologies of sustainability assessment, maximise eco-efficiency and – mimicking nature – reduce the pressure on resources (DG Research/Env, 2010: 5).

As above, eco-innovation is seen as a means towards eco-efficiency, which in turn is a means towards resource efficiency.

A reverse relation also applies: eco-efficiency is understood as an overall objective of eco-innovation (or environmental technologies) that help to minimise the environmental footprint of human activities:

> This will help contribute to the decoupling of economic growth from resource depletion and environmental pollution leading to improved eco-efficiency in comparison to traditional technologies (ibid: 35).

Beyond relative decoupling, the research agenda anticipates absolute decoupling, i.e. lower overall use of natural resources – whose fulfilment will depend on institutional changes:

> Today's environmental challenges make individual incremental innovation insufficient to deliver on time the new techno-economic systems that will be capable of fully decoupling growth from resource depletion. In addition, new business models need to be designed together with the development of new technologies (ibid: 42).

All those objectives informed the call for proposals, 'ENV.2011.3.1.9-2, Development of eco-efficiency meso-level indicators for technology assessment'. A key aim is 'indicators based on the quantitative assessment of ecoefficiency measured at "meso"-level (depending on the case, this may refer to a system, sector or product)'. As expected outcomes of the research:

> The results will provide policy makers a sound knowledge on the impact of socio-technical dynamics as well as a set of indicators that private actors could use to communicate and inform consumers about the eco-efficiency of their system, sector or product (DG Research/Env, 2010: 43).

This call links several aims: to clarify the socio-political-economic processes which influence the adoption of eco-efficiency measures and which likewise influence their wider effects, as well as to develop indicators for those effects. Knowledge about those socio-technical dynamics should complement meso-level indicators for communication and decision-making (refer also Section A.1.6 below on the meso-scale).

A.1.2 Related policy concepts: eco-efficiency, resource efficiency and eco-innovation

Question: How does eco-efficiency relate to other policy concepts? What has been their relative roles in policy documents?

Summary answer: As a policy concept, eco-efficiency has been linked with resource efficiency in various ways, especially for decoupling economic growth from resource usage and pollution, as a means towards sustainable development. Eco-efficiency is often seen as a practical tool for decision-makers. Resource efficiency generally has a broader meaning, implying systemic changes to accommodate environmental limits; it usually encompasses pollution burdens, though not always.

Detailed answer:

In recent years, the eco-efficiency concept has been nearly displaced by resource efficiency. A decade ago, the above concepts were generally related as follows:

> eco-efficiency strategies → resource efficiency → decoupling = sustainable development

In more recent terminological usage, eco-efficiency has been reduced to an adjective, fetishised as a characteristic of things:

> eco-efficient technologies → resource efficiency (or productivity) → dematerialized economy

The adjective has more usually become 'resource-efficient' technologies.

A decade ago sustainable development was implicitly equated with eco-efficiency. Now both terms have become marginal in policy documents. Therefore a study of eco-efficiency needs a clear conceptual link to resource efficiency and decoupling, especially in order to maximize policy relevance.

Eco-efficiency has been linked with resource efficiency and eco-innovation in various policy documents since the 1990s. All three concepts have had changing emphases and meanings. Resource efficiency continues to appear prominently in policy documents; likewise eco-innovation, especially in the Europe 2020 strategy (CEC, 2010, 2011). But eco-efficiency has become less prominent than before, with less clear links to resource efficiency. In worldwide news coverage of generic eco-innovation, resource efficiency has become more prominent than eco-efficiency (EIO, 2011a: 53).

Resource efficiency has a more ambitious scope than eco-efficiency, though the concepts are related. Resource efficiency aims to optimise resource usage. It poses questions of how to 'do more with less'; how production can be decoupled from resource usage and pollution; how production-consumption systems can optimally use resources; and thus how to restructure or relink those systems.

DG Environment defines resource efficiency as an improvement process, also referring to an earlier concept of carrying capacity:

> Resources need to be managed more efficiently throughout their life cycle, from extraction, transport, transformation and consumption, to the disposal of waste. That is why the Commission is pushing for "resource efficiency". This means producing more value using less material and consuming differently. This will limit the risks of scarcity and keep environmental impacts within our planet's natural limits (DG Env, 2011).

Eco-efficiency often is defined as a practical tool, seen as a means towards resource efficiency, though sometimes the concepts have the reverse relation:

> As a practical tool for the business sector, the [eco-efficiency] concept focuses on practices of resource-use attaining economic and environmental progress through more efficient uses of resources and lower pollution. Thus, eco-efficiency is a more general expression of the concept of resource efficiency – minimizing the resources used in producing a unit of output – and resource productivity – the efficiency of economic activities in generating added value from the use of resources. It also incorporates the production of waste (UN ESCAP, 2009: 1).

From the EEA, an early definition links the two concepts as follows:

> Eco-efficiency is a concept and strategy enabling sufficient de-linking of the use of nature from economic activity, needed to meet human needs (*welfare*), to keep it within carrying capacities; and to allow equitable access to, and use of the environment, by current and future generations (Mol and Gee, 1999: 4).

The same document signals diverse and ambiguous accounts, likewise overlapping with resource efficiency:

> … eco-efficiency is a strategy or an approach aimed at de-coupling resource use and pollutant release from economic activity – but current definitions, e.g. from WBCSD and OECD can lead to different interpretations because they involve several concepts such as 'input', 'output', 'pressures', 'impacts', 'resource intensity' etc. (Mol and Gee, 1999: 24).

High-profile Commission documents elaborate various means, aims and benefits of resource efficiency – but rarely define the concept (except DG Env, 2011). Eco-efficiency is generally seen as a means towards resource efficiency. For example, the 6th Environmental Action Programme had the objective: 'To achieve a de-coupling of resource use from economic growth through significantly improved resource efficiency, dematerialisation of the economy, and waste prevention' (CEC, 2001b: 5). Business must do more with less: 'Business must operate in a more eco-efficient way, in other words producing the same or more products with less input and less waste, and consumption patterns have to become more sustainable' (CEC, 2001a: 3). Reiterating earlier concepts, the Renewed Sustainable Development Strategy advocated innovation as a means to resource efficiency: 'Gaining and maintaining a competitive advantage by improving resource efficiency, inter alia through the promotion of eco-efficient innovations' (EU Council, 2006: 13).

Both concepts imply a change in innovation priorities:

> As a key strategic direction to its work on environmental issues, the OECD should begin placing as much emphasis on improving resource efficiency as it has traditionally put on improving labour productivity. This would promote eco-efficiency in the broadest meaning of the term. The OECD should also accelerate efforts to shift some of the burden of taxation from employment and savings to resources and pollution, to decrease the use of perverse and environmentally damaging subsidies, and to integrate more closely environmental with trade and investment rules (OECD, 1997).

A later OECD report links all three concepts, whereby overall eco-efficiency is both an aim and indicator of eco-innovation:

> Decoupling economic growth from environmental pressure: An innovation-oriented environmental policy is necessary to achieve simultaneously ambitious socio-economic and environmental objectives and substantially raise the eco-efficiency of the economy (OECD, 2009: 27).

It discusses sustainable manufacturing indicators, in particular this task:

> Standardise methodologies for material flow analysis at the micro level (*i.e.* at the corporate or product level), as this is considered as one of the most effective tools for improving energy and resource efficiency (OECD, 2009: 34).

According to that report, however, eco-efficiency indicators were not yet consistent or appropriate for decision-making to promote resource efficiency:

> Except for eco-efficiency indicators, each of the nine categories [e.g. key performance indicators, material flow analysis, LCA indicators] is mainly designed to help management decision making or to facilitate improvements in products or processes at the operational level…. Eco-efficiency indicators [ratio of economic value created to environmental impacts] are promising, but those in use have incompatible conceptual approaches (OECD, 2009: 22).

In recent years, EU policy documents have emphasised resource efficiency, while nearly abandoning the eco-efficiency concept. For example: 'Resource efficiency contributes to the goal of creating more value while using less resources' (CEC, 2008: 3), according to the Sustainable Consumption and Production Plan, which does not mention eco-efficiency.

The Europe 2020 strategy promotes 'Resource efficient Europe' to help decouple economic growth from the use of resources, along with 'resource efficient technologies' rather than eco-efficient ones (CEC, 2010: 4). According to its flagship document on that issue: 'By reducing reliance on increasingly scarce fuels and materials, boosting resource efficiency can also improve the security of Europe's supply of raw materials…' Also the shift towards a resource-efficient and low-carbon economy 'will help us to boost economic performance while reducing resource use' (CEC, 2011a: 2).

Europe 2020 flagship documents have similar emphases. *A Resource-Efficient Europe* (CEC, 2011a) does not mention eco-efficiency. *The Eco-innovation Action Plan* does not mention eco-efficiency, while mentioning resource efficiency briefly within a milestone:

> revision of existing water policy, air quality and emission standards, building standards, existing prevention, re-use, recycling, recovery and landfill diversion targets, as foreseen in the frame of the Resource Efficiency Roadmap (CEC, 2011b: 8)

In other key documents, resource efficiency has likewise displaced eco-efficiency. It does not appear in an expert report for DG Environment on resource efficiency (EIO, 2011a), nor in its thematic report on water eco-innovation (EIO, 2011b). The European Environment Agency no longer mentions eco-efficiency per se, e.g. in a recent report on water efficiency (EEA, 2012). The concept appears briefly as 'eco-efficient technologies' when reporting on *Resource Efficiency in Europe* (EEA, 2011).[1] According to the EEA's analysis of policy documents from several countries, resource efficiency has diverse meanings, some overlapping with other concepts:

> Terms such as 'resource efficiency,' 'decoupling,' 'sustainable use of resources' or 'minimising use of natural resources' often seemed to be used as synonyms (EEA, 2011: 8).

Here resource efficiency is linked with the aim to dematerialize the economy:

> Given that EU-wide goals are a strong driver for national policy action, future EU resource efficiency policies could play an important role in defining common EU-wide strategic objectives on resource efficiency, for instance on dematerialising the economy or reducing the dependence on critical materials (ibid: 34).

A recent study for the EEA focuses on technological improvements as a potential means towards resource efficiency. It asks whether eco-efficient technologies are being adopted and whether potential environmental gains are being undermined by changing behavior which increases overall resource usage. As summary answers for each sector:

> Key production sectors have shown a mixed performance in decoupling direct [resource] pressures from growth in output during the period 1995-2006. Public services, agriculture, hunting, forestry and fishing and manufacturing showed best performance with absolute decoupling in all environmental pressures considered, while transport, storage and communication showed poorest performance with continuous growth in all emissions (ETC-SCP, 2011: 48).

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[1] An editor of the 2011 EEA report responded to an e-mail query, as follows:
You hit the nail on the head with the observation that resource efficiency has gained visibility on the policy agenda, while eco-efficiency has perhaps less prominence than before. But I am not really convinced that this is a result of a conscious decision; in my very personal opinion, it is merely a reflection of wording used for policy priorities (personal communication via e-mail, 21.01.12).

Such a focus on eco-efficiency appears as an exception to the overall terminological trend in recent years. For example, a report on eco-innovation briefly mentions eco-efficient life cycles and technologies (Reid & Miedzinski, 2008: vi, 8). The McKinsey report discusses how to promote 'resource-efficient technologies', rather than eco-efficiency, when elaborating the imperative and means of a 'resource revolution' (Dobbs et al., 2011: 83, 131).

A.1.3 Defining eco-efficiency

Question: How to define eco-efficiency? How can this help to evaluate options for improving a system?

Summary answer: Eco-efficiency generally refers to a relationship between socio-economic benefits (or societal welfare) and environmental impacts (or burdens) of the same activities, as a basis for improving that relationship. Often this relationship is expressed as a ratio = economic/environmental parameters, whereby the two components could be calculated for making comparisons among options or over time. As a concept for redesigning production systems, however, eco-efficiency generally has meanings broader than a ratio to be calculated.

Detailed answer:

When eco-efficiency became a prominent concept in the late 1990s, exponents drew on earlier concepts. For example, resource productivity has origins in 1990s efforts at greening business:

> Managers must start to recognize environmental improvement as an economic and competitive opportunity, not as an annoying cost or an inevitable threat. Environmental progress demands that companies innovate to raise resource productivity – precisely the new challenge of global competition. It is time to build on the underlying economic logic that links the environment, resource productivity, innovation, and competitiveness (Porter and van der Linde, 1995).

Such problem-diagnoses informed the 'eco-efficiency' concept as a ratio = economy/resources.

A similar ratio has been called resource productivity (e.g. Mol and Gee, 1999) or environmental productivity (e.g. Huppes & Ishikawa, 2007).

The above ratio is sometimes reversed, as follows:

> Eco-efficiency = environmental performance/financial performance (Ellipson, 2001).
>
> Eco-efficiency = environmental impact per unit of product (Huppes & Ishikawa, 2009: 1688; also 2007).

But the latter ratios are usually called resource intensity or eco-intensity, rather than eco-efficiency. For example: Resource intensity (or material use intensity) looks at the 'consumption of primary and secondary materials per unit of real Gross Domestic Product (GDP) which is calculated for one commodity at the country level'. Its measurement is intended to document total material consumption trends, as well as changes in the consumption patterns, which could bring close the measurement of the real material absorption of the economy (UN ESCAP, 2007).

Either way around, for eco-efficiency or resource intensity, similar issues arise in defining the two components, as described below.

Diverse definitions of eco-efficiency

Question: How do eco-efficiency definitions vary, emphasizing some aspects rather than others?

Summary answer: Each definition involves methodological issues for its specific focus and practical aim, as surveyed above. Eco-efficiency can refer to specific improvements and/or to more ambitious aims, especially decoupling economic activity from environmental impact, as well as enhancing social equity. Some early definitions related environmental impact to 'carrying capacities', though this term has disappeared in more recent documents. Definitions also differ over the breadth of effects. In a narrow account, a ratio reduces welfare benefits to financial advantage of economic operators only, and likewise reduces environmental impacts to measurable indicators of resource usage and pollution. In a relatively broad account of the relationship, 'welfare benefits' should include employment and socio-cultural aspects; likewise environmental impacts can include community amenities.

Detailed answer:

All definitions relate welfare and economic parameters in different ways.

Note the variations in these examples, mainly in chronological order:

- Eco-efficiency = ratio of economic value-added/environmental impact-added (WCED, 1987, cited in Mickwitz et al., 2006).
- Eco-efficiency = 'activities that create economic value while continuously reducing ecological impact and the use of resources' (Schmidheiny, 1992).
- 'Eco-efficiency is the efficiency with which ecological resources are used to meet human needs…' (OECD, 1998: 7).

Eco-efficiency can emphasise social equity within and across generations:

> Eco-efficiency is a concept and strategy enabling sufficient de-linking of the use of nature from economic activity, needed to meet human needs (*welfare*), to keep it within carrying capacities; and to allow equitable access to, and use of the environment, by current and future generations (Mol and Gee, 1999: 4).

Here benefits = human welfare, where products are a means rather than a measure: the numerator is 'a measure of *welfare* deriving more or less from economic activity' (Mol and Gee, 1999: 28).

Eco-efficiency = a perspective for improving production systems.

> Eco-efficiency is a management philosophy that encourages business to search for environmental improvements which yield parallel economic benefits. It focuses on business opportunities and allows companies to become more environmentally responsible and more profitable (WBCSD, 2000: 8).

Eco-efficiency includes measures that avoid or reduce future financial costs (De Simone and Popoff, 2000: 25). [Their extent depends on counter-factual scenarios about what would otherwise be such costs.]

Eco-efficiency = 'producing more (goods and services and value added) with less (resources, waste, and pollution)', according to a book representing the WBCSD (Holliday et al., 2002: 18).

Eco-efficiency has four aspects: dematerialization, production loop closure, service extension, and functional extension (ibid: 85).

Eco-efficiency = output (value added + intermediate consumption) / environmental impact (Seppala et al., 2005).

Eco-efficiency can refer to specific improvements or to decoupling as a more ambitious aim. Benefits result from economic outputs within an improvement process:

> Eco-efficiency is reached by the delivery of competitively-priced goods and services that satisfy human needs and bring quality to life, while progressively reducing the environmental impacts and resource intensity throughout the life cycle, to a level at least in line with earth's estimated carrying capacity. In short, it is concerned with creating more value with less impact (WBCSD, 2006: 3).

Businesses can improve their eco-efficiency through these seven measures: reduce material intensity, reduce energy intensity, reduce dispersion of toxic substances, enhance recyclability, maximize use of renewables, extend product durability, increase service intensity (ibid: 15).

Eco-efficiency must define human needs more broadly than economic criteria:

> At the regional level, social aspects must be included or then the concept of ecoefficiency must be limited to the efficiency with which ecological resources are used to provide economic welfare instead of to 'meet human needs' (Mickwitz et al., 2006: 1604).

Through consultation with local stakeholders in a regional study, 'The process resulted in eight themes describing the socio-cultural dimension of regional development' (ibid: 1608).

Socio-cultural aspects have been measured partly by a study of social well-being. 'For example, the theme ''safety'' is measured by the development of certain crimes, the number of homicides and violent crime, and the number of traffic accidents' (Mickwitz et al., 2006: 1608)

Eco-efficiency is often seen as a means towards decoupling economic growth from environmental burdens, as a policy aim. For example:

> 'Decoupling, as combined economic growth with environmental improvement, is the key ingredient of the definition of eco-efficiency' (CML et al., 2008: 12).

Eco-efficiency = broader than a ratio

Question: In defining eco-efficiency, how to specify the relationship between welfare benefits and environmental impacts, especially towards improvement?

Summary answer: Eco-efficiency has diverse meanings, generally broader than a ratio. They can be listed from the broadest to the narrower:

- An activity, continuous process and/or philosophy for improving the relationship between welfare and environment (especially according to earlier accounts, e.g. Schmidheiny, 1992; OECD, 1998; WBCSD, 2000; WBCSD, 2006, see below; Taylor et al., 2006);

- Specific added benefits and/or reduced environmental impact from process changes (e.g. WCED, 1987);
- A quantifiable ratio as a baseline and/or as a change (e.g. Seppala et al., 2005).

Detailed answer:

Illustrating eco-efficiency as a relatively broad concept: It goes further than environmental management (e.g. pollution control, recycling, prevention) to cleaner production methods (van Berkel, 2008). It has several guiding ideas: zero waste, value enhancement, environmental concern, continuous improvement, creativity & flexibility (Taylor et al., 2006).

Like eco-efficiency in general, its two components (welfare and environment) have diverse meanings, which become narrower through quantification.

Let us first look at variations in socio-economic benefits and environmental burdens – i.e. the numerator and denominator, respectively.

- Socio-economic benefits = human welfare or simply economic outputs?

  For the numerator, some definitions encompass human needs or welfare linked with economic activities (e.g. Mol and Gee, 1999). Going further, a study held workshops to elicit stakeholders' views on socio-cultural aspects of eco-efficiency (Mickwitz et al., 2006). Other definitions focus on tangible outputs of economic activities. For the latter account, emphases have shifted from activities to their measurement per se, by considering only quantifiable parameters (e.g. WCED, 1987 and Seppala et al., 2005). Eco-efficiency measures can reduce current or potential future costs of poor environmental performance, among other economic benefits (De Simone and Popoff, 2000: 25).

- Environmental impacts: what range and consequences?

  For the denominator, impacts include resource extraction, resource usage and pollution broadly defined.

Some definitions run more broadly. For example Huppes and Ishikawa (2007: 25) distinguish among different environmental aspects and consequences:

- *Environmental interventions;* emissions, extractions and land use
- *Midpoint impacts;* main environmental mechanisms such as global warming, acidification and toxicity
- *Endpoint impacts*; items related to human health, environmental quality as an independent value and as the life support system (biodiversity), human affluence (production functions, landscape and cultural heritage)

In such ways, definitions attempt to correlate economic with environmental parameters, thus 'raising subtle but important questions on how to define environmental impact and how to link this to a product' (Huppes & Ishikawa, 2009: 1688; also 2007).

A.1.4 Aggregate indicators?

Questions: If all economic value (or environmental impact) is aggregated into a single number, then what is gained or lost? What are the possible methods for aggregation?

Summary answer: Any aggregation involves cognitive and normative judgements. The process normalizes (standardizes) various parameters for their comparability and assigns relative weights, necessarily dependent on subjective values. Such aggregation can provide a more transparent means to deal with environmental impact indicators, as a basis to facilitate decision-making such as policy support. However, this process loses information that may be important for several aims – e.g. differentiating among effects, for choosing among options, and for engaging wider stakeholders with specific environmental contexts. In particular aggregation marginalises knowledge about interactions, which are crucial for a meso-level analysis.

Detailed answer:

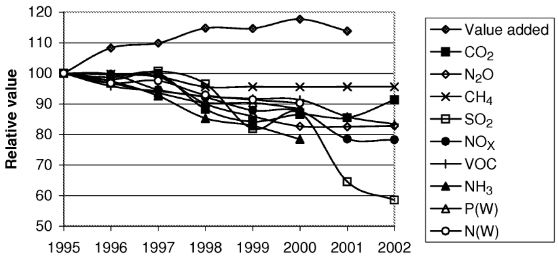
Some writers have criticised aggregation of diverse parameters into standard ones, e.g. on grounds that normalisation loses specific knowledge which is important for decisions. For such reasons, Wursthorn et al. (2011) do not use a single value; to ensure the transparency of results, the environmental impact is presented at the level of various impact categories. As a similar rationale:

> It is very common to transform the economic or the environmental score into a case-specific normalized score, in line with customary approaches in multicriterion decision theory. This practice deletes the information necessary for optimum analysis, as is required in comparing attractiveness of investments in different technology domains and in linking micro-level decisions to macro-level effects (Huppes and Ishikawa, 2005: 39).

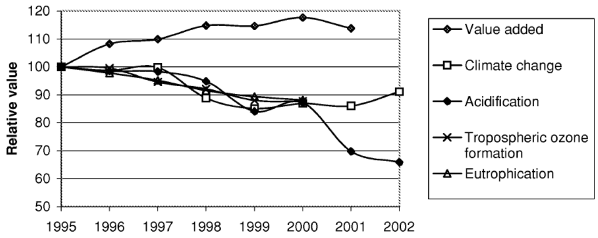
In one attempt at regional eco-efficiency indicators, for example, different economic values were aggregated in money terms. Environmental indicators could be less obviously aggregated, dependent on subjective judgements about their relative importance:

> The use of a total impact value indicator simplifies the complex assessment situation because of the one-dimensional nature of the indicator. But the subjectivity of the results is a weakness of this indicator, although it is constructed using a combination of scientific data (characterization factors and emissions) and subjective weights. The results are sensitive to the values of the weights (Seppala et al., 2005: 126).

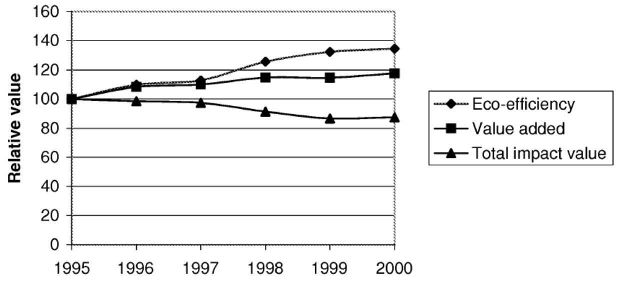
That study does not aggregate environmental impact into a single value because there is no single super-indicator. Hence they present various eco-efficiency indicators related to the equations individually in the same graph (ibid).



(a) Pressure indicators



(b) Impact category indicators



(c) Aggregate indicators

Figure 1: Pressure, environmental impact and aggregate indicators on eco-efficiency

As another criticism, universal indicators may lead people to disconnect them [the indicators] from the environment. On such grounds, a critic advocates reconnection as a normative aim of eco-efficiency:

> … a narrow interpretation of eco-efficiency… focuses on measuring dematerialization with universal indicators…
>
> At the collective level, ecoefficiency builds upon decoupling environmental governance from the local socio-economic and cultural context. By expressing environmental impact simply in terms of mass consumption of natural resources, eco-efficiency creates the illusion that environmental impacts are universally commensurable, regardless of where the impact takes place, and can, therefore, be managed through globally applicable governance systems…
>
> The criterion for adopting eco-efficiency should be the extent to which it promotes the recoupling of human perception of environmental issues with human action on the biophysical environment, and the concomitant recoupling of human capacity for collective local organization with locally crafted ecosystem management (Hukkinen, 2003: 312, 313).

Likewise, aggregation would be inappropriate for socio-cultural indicators of eco-efficiency:

> Weights for this purpose were obtained from regional experts using a questionnaire distributed at the first regional workshop… The different social indicators are, however, so incommensurable and their relative importance so context-specific that such a general weighting would not be justified (Mickwitz et al., 2006: 1608).

Aggregation of environmental indicators has no consensual method or advantage in the literature – and many disadvantages.

A.1.5 LCA methods: relation to the eco-efficiency concept

Question: How do LCA methods relate to eco-efficiency, especially in defining boundaries at the meso level?

Summary answer: For an eco-efficiency analysis, LCA can encompass all relevant environmental parameters, though not economic ones. LCA assesses a service (or product) which is described as a 'functional unit'. This can be identified on any level. To track every flow associated with a product or service's life cycle, LCA is very demanding of data collection and quality, so usually a cut-off point sets a boundary for practicality. For example, it may take into account only direct emissions from a process, not indirect emissions from producing the inputs (or intermediate products) used in the process. LCA can be appropriately designed to fit any system, including meso-scale interactions among heterogeneous actors, processes or systems (see Section A.1.6).

Detailed answer:

Life Cycle Assessment (LCA) is a concept and tool for assessing the environmental impact of a product or service during its lifetime; it is also known as the "cradle to grave" approach. The basis of the LCA concept is an energy and material balance over the system that provides the specific function of a service or product, linking all inputs and outputs to their ultimate origin or fate in natural resources.

The service (or product) under study is described as a 'functional unit', for which the assessment will take place. It can be assessed on any level – for example,

- A product unit, e.g. litre of packaged milk, or
- An entire sector, e.g. all electricity consumption in a country, or all polymers produced in the EU, or a product basket, e.g. annual food consumption for a family, or
- Economy-wide production measured as GDP.

All the material and energy flows associated with the functional unit are tracked from cradle to grave (upstream and downstream) in the defined system, i.e. along the value/supply chain. Materials include all types of substances, e.g. plastics, water, solid waste, SOx, NOx, wood, oil, CO_2, etc. An LCA system may have a functional unit defined as a specific process or product, but the assessment is done at a larger scale, along the value (or supply) chain of the functional unit. The functional unit may be described on any level (e.g. micro, meso, and macro), depending on how those levels are defined.

After the balancing of material and energy flows over the system in an LCA, the flows are quantified and sorted (called classification and characterization) into different environmental impact categories, according to their potential environmental impact. The *impact assessment,* and choice of impact categories, can be carried out according to several methods, which are based on different scientific perspectives on environmental impacts. (Note: they are *not* value-based, which is the case in weighting methods.) There are several categories and methods to choose from; the EU has ongoing work on a set of proposed standard categories/methods, e.g. eutrophication potential, global-warming potential (GWP), tropospheric ozone formation, etc.

The impact-assessment models express environmental impacts for elementary flows, i.e. flows from the technosphere to the biosphere, or from the biosphere to the technosphere. From a set of emissions data (e.g. direct emissions from a single process or aggregated for a group of the same type of process, and not along the whole value chain), one can then apply one of the available impact-assessment models often used in LCA studies. The models classify the emissions into impact categories, where they are translated into a category-specific unit (e.g. kg CO2-eq for the GWP category) and added up into a category indicator (e.g. total kg CO2-eq). These indicators can then be communicated for the environmental profile of the process (or functional unit, in case of an LCA) being studied.

As the above implies, an indicator can have a meso-level role and interpretation without having an LCA in the background. For example, it may take into account only direct emissions from a process, not indirect emissions from producing inputs (e.g. intermediate products or electricity) used in the process. However, an important question arises: if an eco-efficiency indicator counts only direct emissions, then how relevant would it be to the meso level?

Eco-efficiency is a way to correlate environmental impacts with economic value in business or society. This is a difference from LCA, which considers only environmental impacts – not economic costs or values. The definition of eco-efficiency does not imply how to determine the environmental impact (nor how to determine the value), but it seems reasonable to use the same object of study for both the value and the impact. And as argued above, LCA is well applicable for meso-level objects of study. Thus, LCA can be a useful underlying tool for the environmental aspects when working with meso-level eco-efficiency to ensure inclusion of all relevant emissions along the value chain.

Regarding data collection and quality, an LCA is rather data-demanding. Normally, generic average data can be used for the background system and indirect flows, while site-specific data is required for the specific product or service studied. Development of LCA software and databases has facilitated the carrying out LCA studies, but some data collection is generally required.

In an LCA the system boundary specifies which flows will be included and which will not. They lie in several dimensions, for example geographical boundaries, time boundaries, boundaries in relation to natural systems, boundaries within the technical system such as relating to production capital and personnel as well as relation to other products produced in the same process. The boundaries are set by the functional unit, as well as by practicality. Normally, LCA includes all the steps from cradle-to-grave for a product/service, as well as the production of materials &energy used to produce the product/service (e.g. electricity). Since it is data-demanding to track every flow associated with a product or service's life cycle, cut-off criteria are normally set (e.g. labour).

But generally an LCA aims to account for all material and energy flows associated with the life cycle of a product/service. Therefore the system boundaries shall cover all the material and energy extraction, transport, use, and waste treatment steps for product/service (i.e. functional unit) over its life cycle. This will define the system boundaries somewhere between technosphere and biosphere, i.e. when a substance leaves the technosphere and enters the biosphere it counts as an emission/outflow from the system, and so shall be accounted for in one or several environmental impact categories. The opposite holds true for materials/energy entering the technosphere from the biosphere, e.g. raw materials extracted for production.

So while the system boundaries are defined on a case-by-case basis, there is an underlying aim to account for all flows and impacts associated with the functional unit over the entire life cycle. So while the functional unit can be on a micro, meso or macro level, the system boundaries are always set from a cradle-to-grave perspective for the functional unit.

This paragraph is based on the work of [Baumann et al. 2004, JRC 20120a and b.]

A.1.6 Meso-level scale: why? where?

Questions: Why study eco-efficiency at a scale intermediate between the micro and macro? How to identify such a scale? (See each sub-section for summary answers.)

Why an intermediate level?

Question: Why study eco-efficiency at the meso level – also called the intermediate level?

Summary answer: The literature gives several reasons, for example:

- Socio-technical dynamics of innovation: Drivers for eco-efficiency measures, and likewise interactions which influence their adoption, cannot be readily identified at the micro or macro level alone. See again section 1.1.1 above.
- Interactive environmental effects: Macro-level eco-efficiency gains do not simply add up micro-level improvements – e.g., because the latter may be undermined elsewhere in the supply chain and/or because such improvements may depend on intermediate-level interactions.

These are illustrated by examples given below.

Detailed answer:

The analysis can distinguish between indicators which may be additive at a larger scale and those which are not.

> Some meso and micro level indicators relate quite directly to the macro level. Value added per sector and emissions per sector add up to the GDP and the total emissions of society, as does regional GDP and regional emissions (CML et al., 2008: 11).

However, causal chains are not always additive:

> In analysing eco-innovation it therefore is essential to distinguish between the micro level 'where the real things happen', and the also very real meso and ultimately macro level, where outcomes may be quite different from singled-out micro-developments, not only in terms of economic growth and decoupling. These three levels of analysis will be subject of different mechanisms and hence different eco-innovation indicators (ibid: 42).

An intermediate-level analysis is necessary to identify drivers of eco-efficiency improvements. Here are two such viewpoints:

> Trying to link the micro level directly to the macro level seems an inappropriate route; macro-level developments play their independent role (Huppes and Ishikawa, 2007: 6-7).

> Yet just as GDP growth rates cannot reveal structural changes of an economy, a highly-aggregated macroeconomic eco-efficiency indicator cannot disclose the underlying forces driving macroeconomic eco-efficiency... To satisfy the demand for information mentioned above, a detailed analysis takes an intermediate scale, the meso-scale, as its starting point… we propose an approach that focuses on the performance of industry classes using a consistent database to analyse the meso-scale pattern of macroeconomic eco-efficiency (Wursthorn et al, 2011: 488).

In the latter account, the meso-level is equated with a specific industry class or sector, but lacking a method to identify internal or external drivers.

As another reason for a larger-scale study, eco-efficiency improvements may be undermined by shifting environmental burdens elsewhere in a supply chain, e.g. across sectors or nations:

> … profit flows between nations, as it does between economic sectors within a nation, and therefore a nation may reduce its impact on the environment within its borders simply by importing resources and exporting waste (York and Rosa, 2003: 279).

Environmental impacts can be transferred and thus concealed via trade, either within or across countries. Thus eco-efficiency depends on which supply chains are included in the unit of analysis. By encompassing diverse but related supply chains, a meso-level analysis can identify whether apparent environmental burdens are truly being reduced across those chains – or rather are being shifted elsewhere.

Likewise improvements may also be outweighed by larger markets. This has happened recently in Europe:

> Generally, considerable progress being made in the eco-efficiency of products, but increased consumption partly or fully offsets these gains (ETC-SCP, 2011: 7).

As a production process becomes more eco-efficient, 'Damage per money unit of consumption decreases, but total damage remains constant' if economic growth continues (Huppes and Ishikawa, 2005: 32).

Thus, greater overall eco-efficiency would be consistent with unsustainable development:

> Individual economic actions are not created in a void but are intricately related. Reducing emissions at one spot may well lead to more than compensating increases in other spots (Huppes and Ishikawa, 2007: 2).

> … ecoefficiency would increase even though the environmental impact increases as long as the economic value increases faster. If ecological resources are unsustainably used from the outset, such a development would definitely not decrease the problem (Mickwitz et al., 2006: 1604).

Eco-efficiency gains have not added up to resource savings. Europe has decoupled materials use from growth in gross domestic product (GDP), but the absolute level of material consumption has increased – by 8% from 2000 to 2007. If imports are included in the accounting, then Europe leads the world in shifting abroad the environmental cost of resource use (EIO, 2011a).

Through a rebound effect, eco-efficiency improvements may lower costs and so stimulate greater resource usage and/or pollution at various points in a supply chain. This limits environmental improvements at a larger scale; even if it has some improvement, it undermines the goal of decoupling. Such an effect is best-documented for energy-intensive systems, especially where energy comprises a large proportion of overall production costs (Maxwell and McAndrew, 2011: 7-8). Such effects have not been studied for most other resources, e.g.:

> For wider resources, potential direct and indirect rebound examples for water saving measures (low flow and grey water technologies) in households were identified; however, these are not officially defined as rebound and could also be seen as unintended consequences (ibid: 10).

This problem has been recognised at a policy level:

> Studies are being carried out on the 'rebound effect' – the idea that the introduction of technology and policy instruments intended to improve environmental efficiency might have the unintended side-effect of increasing consumption (DG Env, 2011).

By contrast to those harmful interactions, benign ones can create positive synergies between micro-level improvements and wider processes reducing environmental impact. An example is resource recycling:

> an interconnected industrial system in which new products evolve out of, or consume, available waste streams, and where processes are in turn developed to produce usable 'waste' (De Simone and Popoff, 2000: 52-53).

Such symbioses include shifts to renewable resources, re-using or recycling by-products, etc. (Mirata & Emtairah, 2005). There have been efforts to identify existing symbioses, leading to more sustainable industrial development (Chertow, 2007). So indicators are needed to measure those symbioses.

In all those ways, a macro-level scale has its own cause-effect dynamics, irreducible to micro-level changes. For such analysis, 'the easy aggregation by addition of technology domains has to be replaced by a causal model, indicating effects of choices and actions' (Huppes and Ishikawa, 2005: 31). For the purpose of decision-making, there is need for better knowledge of cause-effect dynamics:

> One of the key challenges of eco-innovation measurement on an aggregate level is to relate innovation effects in terms of eco-efficiency gains to the resource efficiency indicators, which, in this context, could serve as a reference point for setting long-term eco-innovation targets (Reid & Miedzinski, 2008: 8).

But there is ambiguity about the appropriate method and scale for identifying such cause-effect relations at the meso-level.

Where: how to identify meso level?

Questions: What generally characterizes the meso-level? How to identify such a level for eco-efficiency in each specific case? By what method?

Summary answer: The eco-efficiency literature does not clearly characterise a *meso*-level scale as qualitatively different than a macro-level scale; nor does the literature identify relevant boundaries. For *meso*-level scale, the unit of analysis can be a system, a process, a product, etc. Some literature implicitly assumes that the meso scale is an intermediate-level production volume, geography, etc. But these assumptions provide no analytical method for identifying the meso-scale in one way rather than another. As the most useful definition, the meso level has two main characteristics – actors' interactions and heterogeneous characteristics (Schenk et al., 2006).

Detailed Answer:

There are methodological difficulties in defining the meso scale. Here are some examples and ways forward.

In the study on regional eco-efficiency (Mickwitz et al., 2006; Seppela et al., 2005), it was methodologically not possible to include effects of upstream processes.

> In addition, to describe real changes in the eco-efficiency of a region, it would be important that the interventions and material flow accounts outside the region represent the actual product chains related to the sectors. Currently, however, product-chain-specific data are not commonly available for the various sectors. With the help of total material requirement (TMR), however, the environmental effects of upstream processes ("imports") were roughly included in the assessments in the Kymenlaakso region… This product-chain approach would also require that environmental impact category indicators be calculable using site-specific characterization factors instead of generic ones (Seppala et al., 2005: 127).

The three levels have been distinguished as follows:

> Economic performance can be measured at three main levels: micro, meso and macro and within these measurements could focus on the following:
>
> - Micro: firm, individual, household, product, service, function, need
> - Meso: sector, supply chain, region, product system/service system, infrastructures (eg transport, energy, communications, water), some firms (depending on size, eg perhaps trans-national firms)
> - Macro: economy-wide: nation, economic blocks, global (CML et al., 2008: 57).

In this taxonomy, the meso level may have novel linkages among firms:

> Inter-firm measures link the micro to the meso scale as they are dependent on having some understanding of which firms comprise a sector or product/service grouping (ibid: 60).

But the above characteristics leave ambiguous the appropriate scale for a meso analysis. How/why would a sector or region be a meso level rather than a macro level?

An appropriate scale also depends on the feasibility of data collection:

> It has to be noted that meso level is the most challenging from the point of view of gathering evidence, as it requires information from many agents. The meso level itself is diverse ranging from the product system to the whole sector and

> needs to be analysed with the use of various methods (Reid & Miedzinski, 2008: 22).

Meso-level analysis aims to inform policy 'that can help a transition towards a sustainable energy system', beyond individual technologies (Schenk et al., 2006: 1514). From a study of energy transitions, this paper offers a meso-level definition which has flexible relevance:

> The meso-level [is] characterised by two typical aspects, i.e. dynamics driven by interactions between actors, and heterogeneous characteristics of actors....
>
> The meso-level involves the coupling of individual technologies and groups of actors, resulting in interdependencies and regimes. Coupling should not be confused with aggregation (Dopfer et al., 2004). Meso-level analysis focuses on the dynamic behaviour of the interdependencies of individual system elements, rather than on aggregating individual system elements. The dynamic behaviour of the interdependencies of individual system elements may result in complex behaviour of the over-all system (Schenk et al., 2006: 1505, 1508).
>
> Interdependency dynamics may result in quite different figures than those foreseen based on macroscopic indicators, especially when renewable energy sources are considered (ibid: 1513).

The above paper does not mention eco-efficiency (nor does Dopfer 2004), partly because the authors have a different focus – namely, to theorise cause-effect complexities and changes in economic relationships.

Within the multi-level perspective (MLP), meso-level analysis has sought to identify and explain transitions from one system or regime to another (Geels, 2002, 2004).

> I understand regimes as semi-coherent sets of rules, which are linked together. It is difficult to change one rule, without altering others. The alignment between rules gives a regime stability, and 'strength' to coordinate activities (Geels, 2004).

Socio-technical regimes are defined as 'the locus of established practices and associated rules that stabilize existing systems' (Geels, 2010: 26).

Table 1 describes different characteristics of macro-, meso- and micro levels. Based on Schenk et al. (2006), it provides insight for identifying a scale intermediate between the micro and macro levels.

Table 1: Characteristics of the macro-, meso- and micro levels

Macro	Meso	Micro
- High aggregation level, but might result in lack of structure - Top-down analysis - 'Macro-level energy analysis describe the over-all functioning of systems and is therefore a valuable monitoring and prognostic instrument.' - Neglects heterogeneity of	- Coupling of individual technologies and groups of actors, resulting in interdependencies and regimes - Focus on dynamic behaviour of interdependencies of individual system elements - Focus on dynamic interactions between individual elements of the	- Low aggregation level - Bottom-up analysis (mostly LCA) can have optimistic bias - Favouring disaggregated data - 'Micro-level energy analysis describes the functioning of elements of systems and is therefore a

underlying data; - Unable to foresee any trend-breaking events - Feedbacks are rarely visible	system - Provides additional information on a system's responses to change - Associated with systems analysis - Dominated by feedbacks (→ relation with rebound effects, e.g. energy efficiency improvement) - Insight for long-term planning - Meso level analysis is relevant for policies - Two typical aspects: 1) interdependency dynamics 2) heterogeneous actors 'The heterogeneous actors' aspect of meso-level theory suggests that differential approaches are potentially more effective than uniform approaches.' (p.1514)	valuable evaluative assessment instrument for products.' - Limited information on the interaction of system elements on the overall system performance - Unable to assess changes in the system - Not suitable for scenario studies

A.1.7 Decision making: who should be able to make what decision

Question: How does/can eco-efficiency inform decisions? By whom? How?

Summary answer: According to different literature sources, eco-efficiency indicators are meant for several kinds of decision-making and makers:

- Comparing alternative options to improve a system;
- Allocating resources to specific options;
- Developing policies (e.g. fiscal, regulatory, R&D, green procurement) which can promote or stimulate improvements; and
- Communicating such judgements to wider audiences, e.g. policymakers, industry, investors, consumers, etc.
- Stimulating Corporate Social Responsibility, mostly applicable to multinational companies, which in itself might operate through their scope on a meso-level scale. Eco-efficiency might be a driver for their corporate responsibility to become more sustainable.

Policy-makers have often stated that eco-efficiency does or should inform decisions; see Section A.1. However, there is little evidence of how eco-efficiency has informed specific actors making any specific decision.

Government policy has been seen as essential for driving eco-efficiency measures, according to the World Business Council for Sustainable Development:

> Governments can use various incentives to promote action toward progress and support initiatives to advance eco-efficiency – rewarding the leading-edge companies and putting pressure on the laggards. Incentives to reward eco-

> efficiency will guide innovation in the right direction and create new products and services (WBCSD, 2000: 6).
>
> Business undoubtedly has many opportunities to increase its eco-efficient performance and thereby to help de-couple use of nature from overall economic growth. However, the potential could be really amplified through political measures that reinforce the eco-efficient opportunities business already has (ibid: 24).

It emphasises the need to share responsibility:

> Establishing framework conditions which foster innovation and transparency and which allow sharing responsibility among stakeholders will amplify eco-efficiency for the entire economy and deliver progress toward sustainability (ibid: 7).

Can this mean diffusing and blurring responsibility, rather than assigning it?

Eco-efficiency information needs adapting and focusing for relevance to stakeholders.

A study developed indicators aimed at regional authorities deciding on development pathways:

> Both sustainable development and eco-efficiency are concepts introduced from outside to the local policy context. In order to implement these concepts, they would have to be interpreted and introduced into the local decision-making process (Mickwitz et al., 2006: 1604).

The study categorised three types of decisions for which workshop participants saw eco-efficiency information as useful:

- Decisions of the type that can directly affect the eco-efficiency of Kymenlaakso;
- Decisions of the type in which eco-efficiency indicators are useful background information framing the situation, but in which other more specific information is more central;
- Decisions of the type in which the role of the indicators is mainly to illustrate the term 'eco-efficiency''.(ibid: 1609).

Trade-offs arise between economic growth and environmental burdens in specific technological choices.

> The ultimate aim of eco-efficiency analysis is to help move micro-level decision making into macro-level optimality. This in turn is based on the environmental quality society seeks, given a specific level of economic development, as macro-level eco-efficiency (Huppes and Ishikawa, 2005: 30; also 2007: 16).

But this scenario does not identify any government authority willing or able to make such a judgement on trade-offs, so the decision-maker remains hypothetical.

For decisions within a firm, eco-efficiency has relevance at three stages of the production chain:

- The period when decisions on investments are shaped by the legal and political framework ideologies, and expectations about future developments, where both business and governance institutions matter;

- The adaptation period within a firm when best firms ought to be imitated, where business institutions matter most;
- The period of renewal when incremental learning effects have come to an end and must be superseded by any new innovation where, again, both business and governance institutions matter (Bleischwitz, 2003: 458).

A.2 Frameworks and Indicators: relevance to meso-level eco-efficiency?

In the eco-efficiency literature, most documents implicitly relate to the micro-level changes in a specific production site or else macro-level economy-wide changes, too large for tracing causal relations. So this literature review looks for elements which have relevance to the meso level. Relevant insights can be found also in literature not specifically about eco-efficiency, e.g. general environmental indicators, LCA, etc., as well as interactions central to a meso-level analysis. This review will inform Case Study leaders when choosing meso-level indicators; conversely, the Case Studies will inform a general method for defining meso-level indicators.

A.2.1 Selection criteria for eco-efficiency indicators: available frameworks

Question: What criteria are generally proposed for selecting eco-efficiency indicators (regardless of level or scale)?

Summary answer: Many sources list the following criteria:

- Availability and affordability of high-quality reliable data;
- Representation of the relevant system (depending on boundary definitions);
- Sensitivity to change over time;
- Consistent units of measure;
- Support to management decisions and actions.

But there are different views about whether all indicators must be mutually independent; see below (UC Davis, 2011 versus Niemeijer & de Groot, 2008).

Detailed answer:

An environmental indicator has been described as follows:

> a parameter or a value, which points to, provides information about, or describes the state of a phenomenon/environment/area, with a significance extending beyond that directly associated with a parameter or value (OECD, 1994).

What is the wider significance? According to what criteria?

A distinction can be made as follows: (a) Collective criteria – relating to the full set of proposed indicators; and (b) Filter criteria – informing the selection of individual indicators.

Although these two different criteria are usually conflated in indicator frameworks, they are quite different:

> The second set is exclusive, acting as a filter for potential indicators, whilst the first is inclusive, aimed at ensuring consistency between indicators, correct balance and focus on different pillars, themes and types of indicators, and completeness, clarity and usefulness of the full set. As such the first set reflects

> much of the decisions made for central elements of the framework including scope and vision of SCP and organisational structure (UNEP, 2008: 46).

Seppala et al. propose the following selection criteria:

> First, the indicators should be relevant and meaningful with respect to the value and environmental impacts of a region's (here Kymenlaakso's) activities. Second, the indicators should be measurable and easily achievable. Third, they should be understandable and their use should be transparent. Finally, the value indicators and the environmental impact indicators in the eco-efficiency equations should be consistent with each other (Seppala et al., 2005: 119).

For relevance to decision-making, an eco-efficiency indicator must have (Steen et al., 2009: 3):

- A specific application and scope,
- Sufficient communication capability to be used,
- Feasible data requirements,
- Credible and legitimate methods

An expert study for California (UC Davis, 2011) proposed the following selection criteria*:*

- Availability of high-quality data;
- Long-term data affordability;
- System representation;
- Sensitivity to change over time;
- Independence of indicators from one another;
- Support to management decisions and actions.

Such criteria aim to inform decisions:

> Although all are important criteria, it is possible that a really good indicator does not meet all criteria; however, each indicator should meet most of these criteria. The Framework is intended to support reporting of indicators to a wide array of water and environmental stakeholders, the public, and decision makers to build knowledge and to enhance adaptive decision-making and policy change (UC Davis, 2011: 12).

The 'independence' criterion is less an exclusionary rule than a caveat: for indicators which are causally related, 'the inter‐dependence of some of the other parameters would need to be acknowledged and potentially controlled ‐ for in order to measure the true effect of increased riparian shade on salmon rearing' (ibid: 35).

Aimed at the macro-level national policy, the UN ESCAP report recommends that eco-efficiency indicators (EEI) should be flexible and adaptable to new issues where policy-makers have the options to choose and incorporate other indicators according to their (a) environmental relevance (environmental objective and priorities), (b) structure of the economy (c) data availability and (d) consistency with their national sustainable development strategies (UN, 2009: 8).

On this basis:

> The EEI framework is flexible enough that countries can choose the most relevant indicators based on two major conditions: a) national policy areas where the pursuit of economic growth with less resource consumption and pollution is a priority; and b) the availability of concrete supporting data for assessment (ibid; 24).

Of the above criteria, 'structure of the economy' is clearly macro level, though other criteria may be relevant to the meso level. Further information on this is provided in the next section.

A.2.2 Specific indicators: some options

Beyond selection criteria, many studies propose or use specific indicators. Most look at economic and/or environmental effects which are most relevant to the macro level.

The 1999 EEA report proposes numerous potential indicators for eco-efficiency, as summarised in the table. From these options, Mol and Gee (1999) advocate a limited set of indicators.

Table 2: Indicators suggested by Mol and Gee (1999) for macro and micro-level eco-efficiency indicators

Macro indicators/ methods		**Micro indicators/ methods**			
Economic	Environmental	Economic		Environmental; reduce material consumption, energy use, CO_2 emissions	
Welfare= GDP HDI (Human Development Index ISEW (Index of sustainable Economic Welfare Price, turn-over, service-unit.	MFA (material flow accounting/ analysis) TMR (total material requirements) energy productivity	Value added Sales price		Loss of biodiversity Releases to air/water Eutrophication/ nutrient flow/ water quality Summer smog/ urban issues EII (environmental impact index; electricity consumption and industrial activity)	
		Production	Consumption	Input (resource use)	Output (impact/pollutants)
4S: the economic sub-system is dependent on 4 basic functions of the environment system: Sources (of energy & materials) Sinks (of wastes) Services (water flow regulation, carbon cycling) Space (for living, economy activity & aesthetics)		Influencing technological innovation Cost reductions Policy Eco-tax Tradable permits	Extending the use phase of products Improving (household processes)	Raw-material input Gross land Energy consumption Land-use Water consumption	Greenhouse effect Acidification Ozone depletion Hazardous waste Chemicals
The EEA classifies indicators into 4 groups, by asking: What is happening to the environment? Does it matter? Are we improving? Are we on the whole better off?					

Indicators can be inferred from potential benefits of system changes. De Simone and Popoff (2000) argue that eco-efficiency has seven criteria for systems improvement:

1. Reduce the material intensity of goods and services
2. Reduce the energy intensity of goods and services
3. Reduce toxic dispersion
4. Enhance material recyclability (link to LCA)
5. Maximize sustainable use of renewable resources (solar, biomass, wave, wind)
6. Extend product durability
7. Increase the service intensity of products, e.g. through shared use, multi-functionality, easy upgrading (modular construction).

De Simone and Popoff (2000: 25) identify five categories of financial benefits of eco-efficiency:

1. Benefits from reducing the current costs of poor environmental performance through measures as waste minimization, especially knowing that most potential environmental costs are “potentially hidden”
2. Benefits from reducing potential future costs of poor environmental performance
3. Reduced costs of capital
4. Benefits from increased market share and improved or protected market opportunities; depending on environmental regulations, potential liability claims and customer sensitivity to environmental performance.
5. Benefits from enhanced “environmental” image

Dow Europe developed an “Eco-compass” spider diagram for LCA (see Figure 2). The “Eco-compass” evaluates environmental impact using six indices: mass intensity, energy intensity, health and environmental potential risk, revalorization, resource conservation, and service extension. These are the same parameters as in De Simone and Popoff, 2000, except that durability is part of service intensity, revalorization covering all types of recycling. Each dimension is scored on a scale of 1-5. Score is relative to a base case study with score 2. To ensure that comparisons are fair, each score is based on the environmental impact of delivering a standard unit of service (e.g. 1MB of data-storage).The scale is divided as follows:

0: performance per functional unit decreases by 50% or more
1: performance per functional unit decreases by up to 50%
2: no significant variation from the base case
3: up to 100% improvement per functional unit
4: up to 300% increase in performance per functional unit
5: a more than 300% increase in performance per functional unit

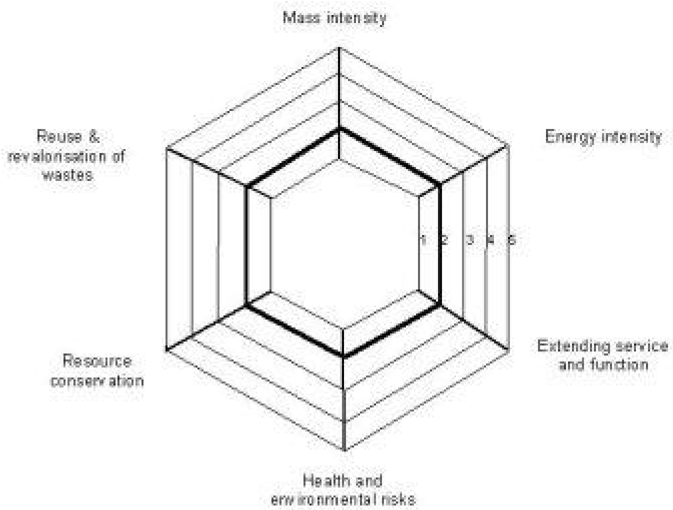


Figure 2: The Eco-compass spider diagram, by Dow Europe and the WBCSD
The closer the shape of the product gets to the outer hexagon, the better it is in terms of environmental performance

Environmental objectives can inform selection criteria. The indicator should include at least one of these aspects: materials, energy, toxic substances, recyclability, the use of renewables, durability and service intensity (WBCSD, 2000). Some of those indicators relate to resource conservation and closed-loop recycling. Among the relevant environmental issues are:

- Consumption of energy
- Materials and water use
- Emission of greenhouse gases and ozone-depleting substances (Wursthorn et al. 2011).

For their regional study, Mickwitz et al (2006) develop indicators based on environmental analysis of the major economic sectors: emissions, land use and resource extraction (pressure indicators), aggregated into impact categories such as climate change and acidification. This is further explained as follows:

> The environmental impact indicators are based on a life-cycle assessment method, producing different types of environmental impact indicators: pressure indicators (interventions) (emissions of CO_2, land use and resource extractions) impact category indicators (CO_2 equivalents, climate change) (in order to help the interpretation of pressure indicators, the inventory data are assigned to impact categories according to the cause-effect relationships of indicators) total impact indicators (aggregating different impact category results into a single value) (Sepalla et al. 2005: 121).

This regional study proposed the distinction of Table 3, as regards feasibility of indicators.

Table 3: Distinction among environmental impact indicators

Impact categories with direct pressure indicators (generally accepted)	Impact categories with indirect pressure indicators (region specific, difficult to monitor/ lack of data)
1. Climate change (carbon dioxide [CO_2], dinitrogen oxide [N_2O], methane [CH_4], chlorofluorocarbons [CFC-11/12]) 2. Stratospheric ozone depletion (CFC 11/12) 3. Tropospheric ozone formation (nitrogen oxides [NOx], non-methane volatile organic compounds [NMVOC], carbon monoxide [CO], CH_4) 4. Acidification (sulfur dioxide [SO_2], NO_x, ammonia [NH_3]) 5. Aquatic eutrophication (phosphorus [P] to water, nitrogen [N] to water, NO_x, NH_3) 6. Oxygen depletion in waters (biological oxygen demand [BOD_7], ammonium [NH_4^+] to water) 7. Ecotoxicity (dioxins, furans, polycyclic aromatic hydrocarbons, cadmium [Cd], lead [Pb],mercury [Hg])	8. Environmental accidents (number of oil and chemical accidents, releases of oil and chemicals) 9. Contaminated soils and sediments(number of contaminated sites requiring remediation, priority class 1) 10. Local air quality (traffic volume, exceedance of PM10 standard values, NOx and SO_2 emissions of manufacture, energy production and traffic) 11. Noise (traffic volumes) 12. Smell (exceedance of total reduced sulfur (TRS) standard values 13. Impacts on biodiversity due to land use (number of plans for enhancing cultural habitats and biodiversity, forest management activities, and so forth, and acreage of plans) 14. Depletion of landscape and cultural environment (as above) 15. Depletion of recreation possibilities (basically as above) 16. Depletion of non-renewable resources (amount of landfilled municipal waste, recovery rate of municipal waste)

The UN ESCAP (2009) framework makes a distinction between types of indicators:

- Scope-wide indicators; covering both economic and sectoral issues; and
- Subject-wise indicators: covering other relevant issues as identified by policy-makers.

Table 4: Framework and set of EEI using monetary output as numerator (UN ESCAP, 2009)

	Resource-use intensity	Environmental impact intensity
Economy-wide indicators		
	Water intensity [m³/GDP] Energy intensity [J/GDP] Land use intensity [km²/GDP] Material intensity [DMI/GDP]	Emission to water intensities [t/GDP] Emission to air intensities [t/GDP] GHG emissions intensities [t/GDP]
Sectoral indicators		
Agriculture	Water intensity [m³/GDP] Energy intensity [J/GDP] Land use intensity [km²/GDP]	CO_2 intensity [t/GDP] CH_4 intensity [t/GDP]
Industry	Energy intensity [J/GDP] Water intensity [m³/GDP] Material intensity [DMI/GDP]	CO_2 intensity [t/GDP] Solid waste intensity [t/GDP]
Manufacturing	Energy intensity [J/GDP] Water intensity [m³/GDP] Material intensity [DMI/GDP]	CO_2 intensity [t/GDP] BOD intensity [t/GDP] Solid waste intensity [t/GDP]
Public and services sector Private ownership but open or accessible to public (commercial, schools)	Energy intensity [J/GDP] Water intensity [m³/GDP] Land use intensity [km²/GDP]	CO_2 intensity [t/GDP] Wastewater intensity [m³/GDP] Municipal solid waste intensity [t/GDP]
Transport sector (use of vehicles only, not manufacturing of vehicles)	Fuel intensity [J/GDP]	CO_2 intensity [t/GDP]

For water-service systems, also needed are indicators which distinguish among types of water use, in particular:

- Emissions to water (e.g. N-eutrophication, toxic waste, acidification, COD, BOD, heat, etc),
- Water as a resource-input (blue/green etc),
- Water as a waste-output “dirty resource” (brown/grey/process).

A.2.3 Selection criteria for meso-level indicators

Question: By what criteria to select indicators for meso-level eco-efficiency? Especially for water-service systems?

Summary answer: To select indicators for meso-level eco-efficiency, the following criteria seem helpful:

- Measurement of meso-level interactions by properly combining their effects, e.g. from upstream inputs to downstream outputs.
- Description of business-as-usual practices, as a basis to anticipate or design improvements and their meso-level effects.
- Distinction between absolute improvement (decoupling) vs. relative improvement.
- Data availability in general, which is a selection criterion in much literature (Wursthorn et al., 2011; UC Davis, 2011).
- Data availability at the appropriate scale, i.e., feasible to collect/measure, and based on standard units (e.g. kg, m^3, EUR).

In this project, meso-level is interpreted to mean interactions – among actors, activities and resource flows. These interactions influence how micro-level eco-efficiency improvements become meso-level effects. Such improvements may be enhanced by synergies, but instead they may be undermined by burden-shifting or rebound effects. Identifying such interactions may depend on the scale, both upstream and downstream of a specific site; such boundaries are about more than simply volume or geographical extent (SeeA.1.6). Indicators are needed to measure meso-level effects of the interactions throughout a water value chain or water-service system. A meso-level indicator should assemble data from several points in the chain or system.

For the meso level, environmental indicators should encompass cause-effect relations. Although not mentioning any specific level, a paper has emphasised the need to identify causal chains and interactions:

> the concept of causal networks can facilitate the identification of the most relevant indicators for a specific domain, problem and location, leading to an indicator set that is at once transparent, efficient and powerful in its ability to assess the state of the environment…
>
> A major benefit of the proposed framework is that it does not consider individual causal chains but tackles the complexities of the real world by looking at causal networks in which multiple causal chains interact and inter-connect (Niemeijer & de Groot, 2008: 14, 24).

As a relatively simple example, societal and market pressures influence inputs to crop production, whose outputs undergo environmental interactions, which in turn can be monitored (ibid: 20). Likewise different production systems can interact.

T1.1 discussions have formulated some preliminary meso-level indicator categories:

- Analytical: indicators that can help to anticipate and/or monitor the above interactions, while also scoping relevant boundaries of a system.
- Operational: indicators that can be used for organizational decision-making as regards specific options for eco-efficiency improvements, e.g. by anticipating the above interactions and designing beneficial synergies.

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Annex B Overview of potential parameters per indicator theme

Climate Change & Global warming / Greenhousegas emissions
CO_2 to air emission
CH_4
CFC
N_2O
Chloride
Average seasonal Temperature
Average seasonal rainfall
Average montly rainfall
Temperature of water

Water availability / Water Quantity
Total volume per year m3/ per season
Abstracted water
Used water per ha
Leakages
Evaporation/Evapotranspiration
Re-used water
Ratio abstracted to returned (discharged)
Used water per capita/per unit
Leackages
Infiltration
Supplied or distributed water
Storage/conveyance/distribution/application losses
Mineral oil

Ecosystem health / Ecotoxity compounds emissions
dioxin
furan
polycyclic aromatic hydrocarbons
cadmium Cd
lead Pb
mercury Hg
Heavy metals (e.g Co,Se,Al,etc)
nickel Ni
zinc Zn
TEH (Total Extractable Hydrocarbons)
chromium IV

Resource availability / (Input) Resources 'Resource use intensities'
Energy - Electricity
Energy - Oil/Gas
Energy - Transport fuels
Surface Water
Groundwater
Other water
Fertilizers
Pesticides
Chemicals / Dye
Land use / land claim
Dairy
Soil
Insulation of pipes
Dolomite (crushed)
Sand
Raw milk
Detergents
sanitisers
Refrigerants
packaging materials
Chemicals for groundwater treatment

Waste / Solid waste
Waste to landfill
Waste to incineration plant
Waste to recycling plants
Sludge (olive oil products)
Used sludge - fertiliser
Used sludge - other
Used olive core
Waste conversion into resource

Ozone hole / ozone-reducing compounds - emissions to air
NO_x
NMVOC (nonmethane volatile organic compounds)
CO
CH_4
CFC
CO_2

Receiving Water Quality / Emissions
NO3
NH4
N Total
PO4
P Total
BOD (Biological oxygen demand)
COD (Chemical oxygen demand)
Total Pesticides and Fertilizers
TSS (Total Suspended Solids)
pH
SAR (Sodium Adsortion Ratio)
Microorganisms (e.g coliform)
Microbiological contaminations
Micropollutants
Nanoparticles
Temperature (gradient)
Electrical Conductivity (EC)
chlorides
surfactants
sulfates
chromium and metals

Biodiversity
habitat variety
inventory flora variety
inventory fauna variety

Soil health and productivity
Soil Organic Carbon

Acidification (emissions to air) / Acidifying emissions
SO2
NOx
HCl
NH3

Health / Air Quality - emissions to air
number of days of pollution
SO2
NO2
NH3
NMVOC (nonmethane volatile organic compounds)
Milk powder dust
refrigerants
odeur

Annex C Literature Overview

This annex provides an overall overview of literature that we identified during the development of Deliverable 1.1. This overview also includes literature that may be relevant to other activities within the Eco-Water project or other projects. It may serve as a starting point for other studies.

Document	Comments
i. Eco-efficiency in general	
Schmidheiny (1992) *Changing Course: A Global Business Perspective on Development and Environment*.	Antecedent of WBCSD 2000 report.
WBCSD (2000) *Eco-efficiency: Creating More Value with less impact*. also WBCSD (2006) Eco-Efficient Leadership. WBCSD (2000) Measuring eco-efficiency	Widely quoted business agenda for eco-innovation towards an eco-efficient economy. Warns that improving eco-efficiency does not automatically lead to greater environmental sustainability, which needs extra measures.
OECD (1998) *Eco-efficiency*.	Early framework emphasising how ecological/envtl resources 'are used to meet human needs'. The full potential for improving eco-efficiency 'is only likely to be achieved through coherent government policies for sustainable development.'
EEA (1999) *Making Sustainability Accountable: Eco-efficiency, Resource Productivity and Innovation*, Topic report No 11/1999, European Environmental Agency.	pp.27-31: eco-efficiency as a ratio = welfare/use of nature; elaborated along various lines, e.g. Sustainable Human Welfare, Material Input per service unit (MIPS), etc. See also pp.1-4 on policy context and pp.15-16 for workshop discussion on indicators.
Michelsen, O. (2006) *Eco-efficiency in Extended Supply Chains – Methodological development with regulatory and organizational implications*, Thesis.	Mentions a wide range of environmental issues, esp. forestry & land-use impacts on biodiversity
Michelsen, O. (2006) Eco-efficiency in extended supply chains: a case study of furniture production, *Journal of Environmental Management* 79(3): 290-297	See above: 'a small and realistic change of end-of-life treatment significantly changes the eco-efficiency of a product'.
De Simone, L. and F. Popoff (2000) *Eco-efficiency: The Business Link to Sustainable Development*. Cambridge, MA: MIT Press.	Widely quoted definitions of resource efficiency and eco-efficiency Eco-efficiency can act as a useful tool for reporting and monitoring performance. The defined benefit is reducing current and potential future costs of poor environmental performance.
Schaltegger, S. (1996) *Corporate Environmental Accounting*, John Wiley	Early, broader definitions of eco-efficiency

Document	Comments
Huppes, G. & Ishikawa, M. (2005) A framework for quantified eco-efficiency analysis, *Journal of Industrial Ecology* 9(4): 25-41.	Attempts to link micro-level eco-efficiency decisions with optimal macro-level outcomes, generally dependent upon standardised criteria and normatively based trade-offs. Discusses difficulties of a fully causal analysis.
Huppes, G. & Ishikawa, M. (2009) Eco-efficiency guiding micro-level actions towards sustainability: Ten basic steps for analysis, *Ecological Economics* 68: 1687–1700.	Explains why a focus on micro-level technological change makes over-optimistic assumptions about larger-scale improvements. Elaborates models for several aspects/factors which influence overall outcomes.
Wursthorn, W. (2011) Economic and environmental monitoring indicators for European countries: A disaggregated sector-based approach for monitoring eco-efficiency, *Ecological Economics* 70(3): 487-496.	Elaborates the concept 'environmental intensity' as an eco-efficiency indicator for specific sectors
Hukkinen, J. (2003) From groundless universalism to grounded generalism: improving ecological economic indicators of human environmental interaction, *Ecological Economics* 44: 11-/27.	Criticises a universalistic tendency in eco-efficiency indicators, e.g. for detaching human beings from the ecosystem services; instead advocates sensitivity to context-specific ecosystem implications in the development of such indicators
Huesemann, M.H. (2003) The limits of technological solutions to sustainable development, *Clean Technologies and Environmental Policy* 5: 21-34,http://engineering.dartmouth.edu/~cushman/courses/engs171/Limits-to-Sustainability.pdf	'At best, enhancements in eco-efficiency can buy some time for social and ethical action to address the underlying causes... improvements in eco-efficiency alone will not guarantee a reduction in the total environmental impact if economic growth is allowed to continue.'
Carlson R (2009) Eco-Efficiency: The conceptual model, the concept model and an operational data structure, CPM Report 2009: 2, CPM – Center for Environmental Assessment of Product and Material Systems, Göteborg: Chalmers University of Technology, http://lifecyclecenter.se/wordpress/wp-content/uploads/2011/01/2009_2.pdf	The report presents a detailed model at 4 different levels, with consecutively increasing level of detail: Eco-efficiency conceptually: an informal description of the meaning and the intentions of eco-efficiency, and describes how eco-efficiency is applied, presented and interpreted. The concepts of eco-efficiency: a formal description of the concepts of eco-efficiency and their semantic, functional and logic relations. The information of eco-efficiency: a general overview of the information needed to calculate and present an eco-efficiency value. The data of eco-efficiency: a detailed overview of each individual data item needed to calculate an eco-efficiency value.
Hertin, J. et al. (2004) Assessing the link between environmental management systems and the environmental performance of companies: An eco-efficiency approach, in Klaus Jacob, Manfred Binder and Anna Wieczorek (eds) *Governance for Industrial Transformation*. Proceedings of the 2003 Berlin Conference on the Human Dimensions of Global Environmental Change, Environmental Policy Research Centre: Berlin. pp. 459-478, http://userpage.fuberlin.de/ffu/akumwelt/bc2003/proceedings/	

Document	Comments
459-%20478%20hertin.pdf	
ISO (2011) ISO/FDIS 14045: Environmental management: Eco-efficiency assessment of product systems – Principles, requirements and guidelines	This standard seems to be under development, not really any literature ready. Better info on Life Cycle Website: http://lct.jrc.ec.europa.eu/index_jrc
Aumann, C. (2009) Taking Action to Improve Corporate Sustainability with Eco-Efficiency Initiatives. Alberta: Eco-Efficiency Action Project.	
BENGT STEEN, RAUL CARLSON,FREDRIK LYRSTEDT, GUY SKANTZE (2009) Sustainability management of businesses through eco-efficiency – an example, CPM Report No. 2009:3	Abstract: In 1991 the World Business Council for Sustainable Development were looking for a single concept to sum up the businesses influence on sustainable development. They found eco-efficiency to be suitable. Since then this concept has been used in many ways. This article reviews the conceptual understanding of eco-efficiency, formulates success criteria for an eco-efficiency indicator, gives an example of an eco-efficiency indicator, uses it in a case study, evaluates its compliance with success criteria and indicates its use in sustainability management. It concludes that 1) linking eco-efficiency to economic accounting and the budget process allows for monitoring and management of sustainable development of a business unit and 2) using monetised environmental externalities as a measure of environmental impact in eco-efficiency indicators increases understanding, in that it offers more benchmarks than conventional physical impact measures.
ii. Meso-level eco-efficiency indicators: general	
Schenk, N.J. (2006) *Modelling energy systems: methodological exploration of integrated resource management*. Dissertation. ISBN 90-367-2730-8	See next item.
Schenk, N.J. et al. (2007) Meso-level analysis, the missing link in energy strategies, *Energy Policy* 35: 1505–16.	Meso level = interactions among heterogeneous actors, and interdependencies (causalities, trade-offs, feedbacks, etc.) among various activities
CML/PSI/CSM (2008) Eco-Drive: A framework for measuring eco-innovation: typology of indicators based on causal chains, Final Report, FP6-2005-SSP-5-A	Distinguishes between micro, meso and macro levels for analysing eco-efficiency.
Pillet, G., Maradan, D., Mayor, K, Stephani, E and Zenn, K. (2005) Meso Environment- Economic Analyses; Methodology and main results- industry and urban communities in Arab Countries, draft paper for SMIA conference, Genève.	
iii. Frameworks meant for practical application	
Mickwitz, J. et al. (2006) Regional eco-efficiency indicators: a participatory approach, *Journal of Cleaner Production* 14: 1603-	Finland case study: eco = ecological and economic performance.

Document	Comments
11.	Eco-efficiency measures:' the efficiency with which ecological resources are used to meet human needs.' Looking at a regional level implies: social and cultural aspects (such as resources, employment, safety) environmental (vulnerability towards environmental pressures such as eutrophication), pressure indicators (emissions of CO2, land use and resource extractions) impact category indicators (CO2 equivalents, climate change), economic (such as transport, seaports), natural resource consumption (total material requirement (TMR) direct material input (DMI).
Melanen, M. et al. (2004) *Measuring Regional Eco-Efficiency – Case Kymenlaakso*. ECOREG Project. ISBN 952-11-1900-4	Method uses life-cycle inventory analysis (LCIA) databases to calculate eco-efficiency of each sector. Unclear how these could be causally linked with micro-level eco-efficiency measures. Basis for Seppala paper.
Seppala, J. et al. (2005). How can the eco-efficiency of a region be measured and monitored? *Journal of Industrial Ecology* 9(4): 117-130	See previous item (Melanen et al). Evaluates strengths & weaknesses of various envtl indicators and of subjectively aggregating them into a single value.
van Berkel. R. (2002) 'The application of life cycle assessment for improving the eco-efficiency of supply chains', Proceedings of Muresk 75th anniversary conference, Perth, pp.1-16. http://gis.lrs.uoguelph.ca/agrienvarchives/bioenergy/download/LCA_vanberkel_au.pdf	Wide range of environmental issues relevant to the agribusiness sector. This reference is somewhat old in terms of LCA. Since then the LCA methodology has developed further, and is now a widely used tool, both on product (micro) and systems level (meso?). However, LCA has a few indicators as outcome (e.g. water use or emissions to water), but economic value of product/functional unit generally not included.
Van Berkel, R. (2007) Eco-efficiency in the Australian minerals processing sector, *Journal of Cleaner Production* 15: 772-781.	Clean Production and EE initiatives have expanded since 2003, partly in response to shortages in water and power supplies, but the expansion has reached limits; relevant to T1.4
NRTEE (2001) *Calculating Eco-efficiency Indicators: A Workbook for Industry, National Round Table on the Environment and the Economy*, Renouf Publishing,	Elaborates indicators of materials intensity — energy, water and waste.
Muller, K. and Sturm, A. (2001) *Standardised Eco-efficiency Indicators*, Ellipson.	Proposes specific eco-efficiency indicators, advocates the need to standardise them and identifies accounting issues for doing so. Conversion factors on how much CO_2 and non-renewable energy gets from 1kWh used energy (page 23). Suggested generic indicators.
Kuosmanen, T. (2005) Measurement and analysis of eco-efficiency, *Journal of Industrial Ecology* 9(4): 15-18.	
iv. Eco-efficiency indicators and assessment methodologies	
Zhaoa, W., Huppes. G., Voet, E. van der (2011) Eco-efficiency for greenhouse gas emissions mitigation of municipal solid waste management: A case study of Tianjin, China, *Waste Management*	Emphasises GHG emissions of a specific MSW management system, as well as a set of alternative scenarios to investigate trade-offs between economic value and GHG emissions reduction. See also under Urban cases.

<table>
<tr><th colspan="2">Document</th><th>Comments</th></tr>
<tr><td colspan="2">31(6): 1407-15.</td><td></td></tr>
<tr><td colspan="2">Kobayashi Y., Kobayashi H., Hongu A., Sanehira K. (2005) A practical method for quantifying eco-efficiency using eco-design support tools, Journal of Industrial Ecology 9(4): 131-144.</td><td>Elaborates quality function deployment (QFD) for product value and LCA for envtl assessment. Examples from industrial production.</td></tr>
<tr><td colspan="2">Saling P, Kicherer A et al. (2002): Eco-efficiency Analysis by BASF: The Method. Int Jnl LCA 7 (4) 203–218</td><td>Methodology of eco-efficiency analysis as implemented by BASF and illustrates the specific procedure using the eco-efficiency analysis of a textile dye (Indigo) as an example</td></tr>
<tr><td colspan="2">Carlson, R. (2009) Eco-Efficiency: The conceptual model, the concept model and an operational data structure</td><td>An ISO-standard for eco.efficiency is under development. Alternative definition: Eco-efficiency = gains/costs</td></tr>
<tr><td colspan="2">Subhas K. Sikdar (2003) Sustainable development and sustainability metrics, AIChE Journal 49(8): 1928–1932.</td><td>Positioning eco-efficiency indicators in the interface of environmental and economic aspects</td></tr>
<tr><td colspan="2">Michelsen, O. (2006) Eco-efficiency in extended supply chains: a case study of furniture production, Journal of Environmental Management 79(3): 290-297</td><td>A methodology to assess the eco-efficiency for extended supply chains. Eco-efficiency must not be misinterpreted as sustainability since eco-efficiency only deals with relative and not absolute values, and does not incorporate social issues.</td></tr>
<tr><td colspan="2">Eurostat, (2001) Eco-Efficiency Indicators as a Step to Indicators Of Sustainable Development?, Joint ECE/Eurostat Work Session on Methodological Issues of Environment Statistics (Ottawa, Canada, 1-4 October 2001)</td><td></td></tr>
<tr><td colspan="3">v. LCA water</td></tr>
<tr><td colspan="2">Boulay, Anne-Marie, Christian Bouchard, Cecile Bulle, Louise Deschênes & Manuele Margni (2011) Categorizing water for LCA inventory, Int Jnl Life Cycle Assessment 16: 639–651</td><td></td></tr>
<tr><td colspan="2">J. W. Owens (2002) Water resources in life-cycle impact assessment: considerations in choosing category indicators, Journal of Industrial Ecology 5(2): 37-54</td><td></td></tr>
<tr><td colspan="3">vi. Sector-specific (agriculture/ industrial/ water) literature</td></tr>
<tr><td rowspan="2">Agriculture (general)</td><td>Keating, B., Peter S. Carberry, Prem S. Bindraban, Senthold Asseng, Holger Meinke, and John Dixon (2010) Eco-efficient agriculture: concepts, challenges and opportunities, Crop Science 50, March–April: 109-19,</td><td>Eco-efficiency gains can be achieved through agro-technical solutions, e.g. ‘fundamentally changing the way rice is grown can lead to drastic water savings’ → T1.2 (p. 115)
Mentioned technologies/techniques: biodegradable mulches, nitrification, inhibitors, removing subsoil constraints, ameliorating subsoil acidity, gene technologies, forecasting systems linked with crop simulation models</td></tr>
<tr><td>Narayanaswamy, V. et al. (2005) Application of life cycle assessment to enhance eco-</td><td>Discusses three comprehensive ‘paddock-to-plate’ (farm-to-fork) LCA case studies, viz, wheat-to-bread, barley-to-beer, and canola-to-cooking oil. Show how LCA findings can be strategically linked to practical</td></tr>
</table>

Document		Comments
	efficiency of grains supply chains	eco-efficiency targets at the sub-system or process level. Focuses on LCA impact categories. Discusses which impacts needs focus on when implementing eco-efficiency of agri-products. No discussion on economic value. *Note: this version of the paper is the peer reviewed, not the final published*
	Andrés J. Picazo-Tadeo, José A. Gómez-Limón and Ernest Reig-Martínez; Assessing farming eco-efficiency: A Data Envelopment Analysis approach	
Dairy	Basset-Mens. C, S. Ledgard, and M. Boyes (2007) Eco-efficiency of intensification scenarios for milk production in New Zealand, *Ecological Economics* 68: 1615–25.	Shows how low-input system have higher eco-efficiency than intensive systems, which thereby could be improved
	Weidema et al. (2008) *Environmental Improvement Potentials of Meat and Dairy Products*, Ispra: JRC	pp.33-50: wide range of envtl media and issues; pp.61-69: rebound effects & synergies; pp.75-84: economic indicators, covering a wide range; pp.38-51: improvement options
Industry	Bob Pagan and Penny Prasad, UNEP Working Group for Cleaner Production, *Eco-efficiency, Water Conservation and* *Food Processing in Australia*	
	Cramer, J. and van Lochem, H. (2001) The practical use of the 'eco-efficiency' concept in industry: The case of Akzo Nobel, *Journal of Sustainable Product Design* 1: 171–180.	
Urban	Zhaoa, W., Huppes.G., Voet,E. van der (2011) Eco-efficiency for greenhouse gas emissions mitigation of municipal solid waste management: A case study of Tianjin, China, *Waste Management* 31(6): 1407-15	Emphasises GHG emissions of a specific MSW management system, as well as a set of alternative scenarios to investigate trade-offs between economic value and GHG emissions reduction.
	Palme, U., (2007) The Role of Indicators in Developing Sustainable Urban Water Systems, PhD thesis, Department of Energy and Environment, Environmental Systems Analysis, Chalmers university of technology, Göteborg, Sweden, 2007,	

Document		Comments
	Palme, U; Tillman, A-M (2008), Sustainable development indicators: how are they used in Swedish water utilities? *Journal of Cleaner Production*, 16(13): 1346-1357	
vii. Rebound effects		
Polimeni, J.M., Mayumi, K., Giampietro, M., Alcott, B. (2007) *The Jevons Paradox and the Myth of Resource Efficiency Improvements*, London: Earthscan. Review: Schneider, F. (2010) *Journal of Cleaner Production* 18: 600–602.		Analyses contexts & factors whereby eco-efficiency improvements have been undermined at a larger scale; also various assumptions necessarily involved in efficiency indicators. Schneider review summarises key points.
Maxwell, D. and McAndrew, L. (2011) *Addressing the Rebound Effect*		Approaches for measuring rebound effects, though focusing more on consumer-household behaviour than industrial-operator behaviour. UK Homes – 'water saving' improvements in attaining higher grades within the UK Code for Sustainable Homes **Summary:** This example shows how well intended water saving policy measures within the UK 'Code for Sustainable Homes' can result in the installation of too low-flow rate products/appliances. The unexpected consequence of this is the disillusionment of occupiers and the tendency to replace the low-flow products with much higher flow-rate models, hence resulting in a much higher water and energy use overall. This is an unintended consequence which can be considered a rebound effect (rebound by reversion) in that a policy that pertains to reduce water and energy use, inadvertently may result in higher water/energy use.
Sorrell, S. (2009) Jevons' Paradox revisited: The evidence for backfire from improved energy efficiency, *Energy Policy* 37: 1456-69.		Historical evidence of how eco-efficiency improvements have led to greater resource usage
Schipper, L. & Grubb, M. (2000) On the rebound? Feedback between energy intensities and energy uses in IEA countries, *Energy Policy* 28: 367-388.		Key measures of economic activity (car use, manufacturing output and structure, house area, etc.) have changed little in response to changes in energy prices or efficiency, instead continuing their long term evolution relative to GDP or other driving factors.
Mickwitz, J. et al. (2006) Regional eco-efficiency indicators: a participatory approach, *Journal of Cleaner Production* 14: 1603-11. [also listed above]		Problem: 'Eco-efficiency may increase even if the use of ecological resources is increasing, as long as the indicator of how human needs are met is increasing more rapidly.'
Holm, S., Englund, G. (2009) Increased ecoefficiency and gross rebound effect: Evidence from USA and six European countries 1960–2002, *Ecological Economics* 68(3): 879-887.		Greater ecoefficiency has been associated with economic growth which increases global ecological footprints, esp. by accounting for all relevant resources.

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Alcott, B. (2005) Jevons' paradox, *Ecological Economics* 54(1) 9-21.	Surveys current debate on rebound effects in the light of Jevons' original insight.
York, R. & Rosa, E. (2003) Key challenges to ecological modernization theory, *Organization & Environment* 16(3): 273-288.	Micro-level eco-efficiency improvements may be undermined elsewhere in a supply chain
viii. Related concepts, e.g. LCA, ISO Carbon and water footprint, EU footprint, water resource efficiency and eco-innovation	
OECD (2008) *Measuring Sustainable Production*,	Deals with energy efficiency but less clearly about eco-efficiency
OECD sustainable manufacturing indicators	Emphasises resource-inputs, pollution and recycled outputs, but not eco-efficiency indicators.
JRC (2007) *Recommendations for Life Cycle Based Indicators for Sustainable Consumption and Production in the European Union*, Workshop report, Joint Research Centre,	LCA indicators of resource efficiency, more than about eco-efficiency. No quantitative indicators presented.
CEC (2011) *Innovation for a Sustainable Future: The Eco-innovation Action Plan (Eco-AP).* Brussels: Commission of European Communities,	Emphasises eco-innovation as means to resource efficiency: 'Environmentally safe and energy- and resource-efficient products, processes and services are increasingly enlarging a competitive advantage across many businesses and sectors.' Relevant to T1.2
CEC (2011) *A Resource-Efficient Europe: Flagship initiative under the Europe 2020 Strategy*	Emphasises 'the main aim to decouple economic growth from resource use and its environmental impact'. Needs 'a significant transition in energy, industrial, agricultural and transport systems'. Discusses ways of exploiting synergies and addressing trade-offs.
AquaStress project, Water Stress Framework Tool	Method to evaluate water quality& quantity in relation to demand.
EEA (2011) *Resource Efficiency in Europe*	Surveys diverse meanings of resource efficiency in recent policy documents of EU and member states; meanings overlap with other concepts, but little is said about eco-efficiency.
JRC (2007) *Recommendations for Life Cycle Based Indicators for Sustainable Consumption and Production in the European Union*, Joint Research Centre, http://lct.jrc.ec.europa.eu/assessment/projects	
JRC (2010) ILCD Handbook: Framework and requirements for LCIA models and indicators, First edition March 2010. European Commission – Joint Research Centre – Institute for Environment and Sustainability, EUR 24586 EN. Luxembourg. Publications Office of the European Union;	Good reference literature on LCA.. JRC site: http://lct.jrc.ec.europa.eu/assessment

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2010http://lct.jrc.ec.europa.eu/pdf-directory/ILCD-Handbook-LCIA-Framework-requirements-online-12March2010.pdf	
JRC (2011) *International Reference Life Cycle Data System (ILCD) Handbook*: Recommendations for Life Cycle Impact Assessment in the European context. First edition November 2011. European Commission-Joint Research Centre – Institute for Environment and Sustainability, EUR 24571 EN. Luxemburg. Publications Office of the European Union.	Good reference literature on LCA. .JRC site: http://lct.jrc.ec.europa.eu/assessment
Bleischwitz, R. (2003) Cognitive and institutional perspectives of eco-efficiency, *Ecological Economics* 46: 453-467.	Eco-efficiency measures rely upon institutional-cognitive capacity to evolve in ways appropriate to enhance technological change, involving cooperation and competition. Relevant to T1.4.
EIO (2011) *Water Innovation: How eco-innovation can contribute to the sustainability of Europe's water resources*, Eco Innovation Observatory	Key challenges for water eco-innovation: (page 23) have been set by groups (abstraction, treatment, water supply net, users, and wastewater treatment). Could be used in the next stage of the project for new technologies implementation. Further, innovative technologies are listed. Drivers and barriers of eco innovations at meso -level (page 49).
Groningen, R, *Modeling Energy Systems: A methodological exploration of integrated resource management*, PhD Thesis	
UN (2007) *Eco-efficiency: A practical path to sustainable development*, UN Publication	Definition of eco-efficiency; The United National Conference on Trade and Development (UNCTAD) has developed a set of guidelines for enterprise who wish to develop eco-efficiency indicators as part of their annual accounting. An indicator for eco-efficiency is the "ratio between and environmental and a financial variable. It measures the environmental performance of an enterprise with respect to its financial performance" (UNCTAD, 2004). For each of these areas, UNCTAD presents a methodology for calculating, recognizing, measuring, and disclosing the following five indicators: (a) Water consumption per net value added; (b) Global warming contribution per unit of net value added; (c) energy requirement per unit of net value added; (d) dependency on ozone-depleting substances per unit of net value added; (e) Waste generated per unit of net value added. ESCAP State of Environment 2005 publication identified some potential eco-efficiency indicators, which examine resource use intensity, resource productivity, environmental impact intensity, pressure on carrying capacity, and the rate of resource savings of benefit accumulation (figure 2.5).
UN (2009) *Eco-efficiency indicators: Measuring resource-use efficiency and the impact of economic activities on the environment*, UN publication	Interesting Fig.1 on what is eco-efficiency

Document	Comments
UNEP (2011) *Decoupling Natural Resource Use and Environmental Impacts from Economic Growth*, A Report of the Working Group on Decoupling to the International Resource Panel. United Nations Environment Programme	
Caffoor, I. UN (2008) Business case 3: Energy efficient water and wastewater treatment, Environmental knowledge transfer network	
Caffoor, I. (2008) Business case 4: towards chemical free water and wastewater treatment, Environmental knowledge transfer network	
Thomas, K. (2010) *A vision for a low carbon water sector in 2050: A priority for the UK*, Knowledge Transfer Network	Evaluation of new technologies - Heating water constitutes 25% of total energy consumption in the home and accounts for 89% of CO2 emissions associated with water, i.e. 35m tonnes GHG (Environment Agency, 2009). Reductions in shower duration and dishwasher and washing machine water consumption will be seen as crucial to reducing the carbon footprint associated with water.
Canada (2001) *Eco-efficiency indicators as a step to indicators of sustainable development*, Working Paper N10, Statistical Commission and Economic Commission for Future, Canada	Eco-efficiency criteria of the World Business Council for Sustainable Development 1. minimize the material intensity of goods and services; 2. minimize the energy intensity of goods and services; 3. minimize toxic dispersion; 4. enhance material recyclability; 5. maximize the use of renewable resources; 6. extend product durability; 7. increase the service intensity of goods and services.
Verfaillie, H.A., Bidwell, R. (2000) *Measuring Eco-Efficiency: A Guide to Reporting Company Performance*. World Business Council for Sustainable Development.	Generally applicable environmental indicators: Energy consumption; Materials consumption; Water consumption; Greenhouse gas emissions Ozone depleting substance; emissions Eco-efficiency = Product or service value/Environmental influence
ISO (2000) International Standard ISO 14042. Environmental Management—Life Cycle Assessment—Life Cycle Impact Assessment. International Organization for Standardization	
Rebitzer, G., Hunkeler, D., 2004. Towards a code of practice for life cycle costing: update on the progress of the SETAC life cycle costing working group, *Setac Globe* 5 (3): 60–61.	

Document	Comments
ETC-SCP (2011) *Progress in Sustainable Consumption and Production in Europe: Indicator-based Report*. European Topic Centre on Sustainable Consumption and Production: ETC/SCP working paper 1/2011.	Links eco-efficiency with resource efficiency
Reid, A. and Miedzinski, M. (2008) *Eco-Innovation: Final Report for Sectoral Innovation Watch*, Technopolis,	Surveys other literature on drivers and effects of eco-innovation, including meso-level eco-efficiency.
Berkhout, F. (2011) Eco-innovation: reflections on an evolving research agenda, *International Journal of Technology, Policy and Management* 11(3-4): 191-197.	
Fussler, Claude (1996) *Driving Eco Innovation*, Pitman Publishing.	

IVL Swedish Environmental Research Institute Ltd., P.O. Box 210 60,
S-100 31 Stockholm, Sweden
Phone: +46-8-598 563 00 Fax: +46-8-598 563 90
www.ivl.se