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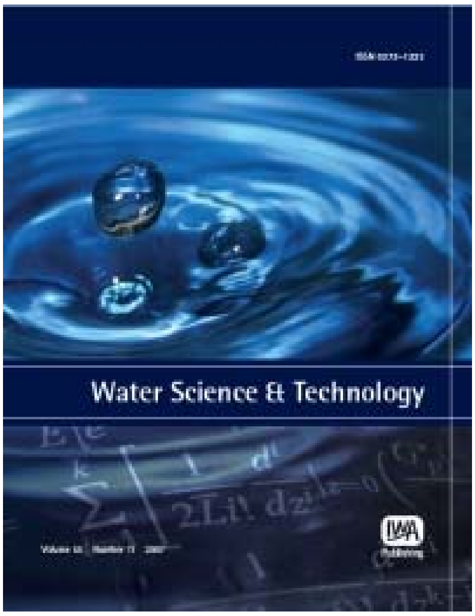
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Les Levidow, Palle Lindgaard-Jørgensen, Åsa Nilsson, Sara Alongi Skenhall and Dionysis Assimacopoulos

ABSTRACT

The well-known eco-efficiency concept helps to assess the economic value and resource burdens of potential improvements by comparison with the baseline situation. But eco-efficiency assessments have generally focused on a specific site, while neglecting wider effects, for example, through interactions between water users and wastewater treatment (WWT) providers. To address the methodological gap, the EcoWater project has developed a method and online tools for meso-level analysis of the entire water-service value chain. This study investigated improvement options in two large manufacturing companies which have significant potential for eco-efficiency gains. They have been considering investment in extra processes which can lower resource burdens from inputs and wastewater, as well as internalising WWT processes. In developing its methodology, the EcoWater project obtained the necessary information from many agents, involved them in the meso-level assessment and facilitated their discussion on alternative options. Prior discussions with stakeholders stimulated their attendance at a workshop to discuss a comparative eco-efficiency assessment for whole-system improvement. Stakeholders expressed interest in jointly extending the EcoWater method to more options and in discussing investment strategies. In such ways, optimal solutions will depend on stakeholders overcoming fragmentation by sharing responsibility and knowledge.

Key words | Arla, eco-efficiency, innovative practices, meso level, Volvo, water-service systems

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INTRODUCTION

As a well-known concept, eco-efficiency has informed efforts to increase economic benefits while also lowering ecological burdens. According to the EU's 5th Environmental Action Programme, '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 2001: 3). It means greater efficiency of economic activities in generating added value from the use of resources, including waste emissions (UN ESCAP 2009: 1).

To be fully operationalised, eco-efficiency denotes a ratio between the economic value and resource burdens of a process. As a ratio, eco-efficiency calculations help to compare any past or future changes with a baseline. Such comparisons can inform investment decisions and government policies influencing them. According to a report from the European Environment Agency, 'eco-efficiency is a strategy or an approach aimed at de-coupling resource use and pollutant release from economic activity' (Mol & Gee 1999: 24).

Eco-efficiency has been generally assessed at the micro level, for example, at a specific site in a company's production processes (e.g. Michelsen *et al.* 2006; van Caneghem *et al.* 2010). This narrow focus neglects wider external effects, especially through interactions between water suppliers, water users and wastewater treatment (WWT) providers. At the other end, macro-level studies have quantified wider changes, for example, in an entire industrial sector or region (e.g. Seppala *et al.* 2005;

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Wursthorn *et al.* 2011), but cannot identify what processes generated them. For promoting strong sustainability as a societal goal of eco-efficiency improvements, 'There is no easy link between micro-level decisions and this ultimate macro-societal reference' (Huppes & Ishikawa 2009: 1698).

This difficult, obscure link has a knowledge gap. It can be filled by identifying causal linkages between innovative practices and the eco-efficiency of a whole system or industrial sub-system. Also called the meso level, this encompasses all the actors and processes resulting in a product, as shown in Figure 1. According to one study, 'the meso level is the most challenging from the point of view of gathering evidence, as it requires information from many agents' (Reid & Miedzinski 2008: 22).

This meso-level knowledge gap leaves open some methodological questions:

- Towards greater eco-efficiency of a whole system, what methods can assess options for innovative practices?
- How can research activity help stakeholders to optimise whole-system eco-efficiency?

These questions will be addressed through the preliminary results of a research project (see 'Acknowledgements'). After describing the methods, this paper shows how they were applied in two case studies, followed by a conclusion answering the above questions.

METHODS AND RESEARCH FOCUS

Our EU-funded research project, EcoWater, develops a methodology and framework for assessing eco-efficiency on the meso level. This level is defined as interactions and interdependencies among heterogeneous actors (Schenk *et al.* 2007), for example, between water-service users and providers, across the entire value chain of the production process (EcoWater 2012). The project develops indicators to compare options for innovative practices, including technology adoption, within a specific water-service system. The latter concept describes any system which gives water a suitable quality and quantity for specific uses, for example, drinking, cooling, industrial processing and irrigation.

By operationalising those concepts, the EcoWater project aims: to assess the eco-efficiency of various options for innovative practices (including technologies), to analyse factors influencing decisions to adopt such practices, to inform better decision-making for meso-level eco-efficiency, and to inform policy frameworks which could promote such decisions. According to Domingo Jiménez-Beltrán, former Executive Director of the European Environment Agency:

> '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' (quoted in WBCSD (2000): 23).

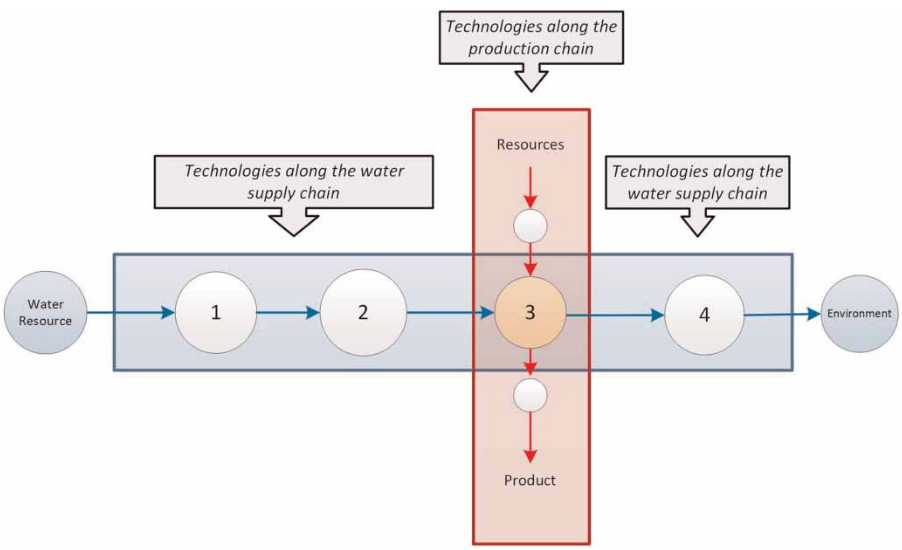

Figure 1 | Potential improvement sites along the meso-level value chain.

Within a meso-level value chain, innovative practices can have several sites and roles:

- Water or production chain, as shown in Figure 1: an innovation can upgrade the water-supply chain (e.g. water inputs or WWT, as in the horizontal axis), or else the production chain (e.g. less resource inputs, lower emissions or reuse of wastes, as in the vertical axis). In the diagram, 'technologies' is shorthand for innovative practices which depend on more than technologies.
- Process or product: within the production chain, process upgrading uses resources in more efficient ways, while production-chain upgrading increases the market value of products.

Such roles can have synergies. For example process upgrading can reduce emissions in wastewater, in turn facilitating improvements in the water-supply chain, for example, through in-house WWT, reuse and recycling.

To explore the potential for eco-efficiency improvements, EcoWater's eight case studies have investigated key actors' perspectives through interviews and workshops. The cases were chosen with several criteria – especially to provide diverse contexts for refining the EcoWater method, and to ensure that adequate relevant data would be available to calculate eco-efficiency effects of several options. Perhaps not by coincidence, companies most willing and able to cooperate with the project had already made significant investment in innovative practices and were considering extra improvements in water-service systems. Impetus has come from companies' environmental policies, as well as from external drivers such as future higher costs and resource scarcity, beyond legislative requirements. Such roles are exemplified by the two case studies in this paper.

Through the EcoWater project methods, a baseline eco-efficiency assessment identified the processes which have the greatest resource burdens and water-based emissions in each case study, for example, in a production plant. These sites became the focus for options which could most improve eco-efficiency. An eco-efficiency ratio has two main components, each with its own indicators:

- Economic: total value added (TVA) to the product by water processes, that is, the water-service value chain. 'Total' denotes the economic value-added minus various costs of water abstraction, treatment, WWT, etc., as well as other resource inputs.
- Environmental: this draws on a standard list of midpoint impact categories, for example, climate change, ozone depletion, eutrophication, human toxicity, eco-toxicity, acidification and resource depletion (JRC 2011).

For the environmental indicators, data came from life cycle assessment (LCA) documents and company sources; economic data came mainly from the company sources (EcoWater 2012). A potential difficulty has been how to obtain adequate, relevant data. Their availability has sometimes guided the choice of specific sites or technological options for the study. Applying the method can be more straightforward for the baseline situation, which already has reliable data from operational experience. For a new technology, by contrast, data may depend on some assumptions and extrapolations.

Each component of eco-efficiency was calculated with a dedicated online tool: Economic Value Chain Analysis Tool and Systemic Environmental Analysis Tool. After refinement through the project's case studies, these tools were made publicly available (EcoWater 2014). The data and calculation methods were discussed with stakeholders providing the information; such calculations are omitted here for lack of space. By estimating the range of uncertainty for indicators, the assessment can establish whether or how uncertainty impedes the main aim – namely, the comparison of technology options with each other and/or with the baseline situation. The comparative method can help stakeholders jointly choose or create better solutions, as explained in the EcoWater project's educational film.

Subsequent sections present such comparisons, as well as multi-stakeholder involvement.

VOLVO TRUCKS: SILANE-BASED OPTION

Volvo's agenda for resource efficiency has driven improvements within the production process. According to the Volvo Group's sustainability report, 'a resource-efficiency approach is well integrated in our culture and is an important priority ahead' (Volvo 2011: 38). Operations attempt to minimise energy use and recycle materials.

> 'We initiated several after-treatment and water recycling projects in Sweden, Belgium and Peru to address the issues, aimed at reducing consumption and effluent emissions … All of Volvo's majority-owned plants have either installed their own treatment facilities or discharge their effluents to external treatment plants. An increasing number of plants are also installing closed process water systems. This is often done when installations

undergo major renovation work, as was the case with the new paint shop project at the Umeå plant' (Volvo 2011: 58).

At each Volvo site, different units have responsibility for economic and environmental evaluation, with some discussion between them. There has been no systematic discussion between Volvo and WWT companies about improvement options. So fragmented responsibilities impede or complicate a whole-system eco-efficiency analysis.

The EcoWater case study investigates improvement options at production units in Tuve and Umeå, which produces truck cabins for the Tuve site. The process of metal surface pre-treatment, prior to applying the surface coating, generally consumes large amounts of water. Closed-loop pre-treatment processes, for example, by re-cycling process water, have been investigated at the Umeå site. Silane-based corrosion-protection techniques have been considered by the Tuve site, which produces frame beams and has a vehicle assembly line. Potential improvements there became an initial focus for the EcoWater study.

Eco-efficiency comparison: silane-based process

In the corrosion-protection process, Volvo Trucks has already made an environmental improvement by replacing a chromium process with zinc-phosphating technology. But the latter still has several environmental disadvantages: it requires heating of process baths, uses heavy metals (Zn, Ni, Mn) which end up in wastewater, and produces hazardous sludge (e.g. metal hydroxides). Relative to those problems, a new silane-based polymer has these advantages: process at room temperature; total energy use ~40% less than the business-as-usual (BAU) process; water use 50–90% less than BAU; no use of heavy metals or P; no hazardous sludge and very little other sludge. Wastewater pollutants (Zr, silane, fluoride) can be reduced to ~0 mg/l by ion exchange.

Thus a potential improvement would be silane-based technology. This substitute has been considered at Volvo's Tuve site. Looking beyond the site, silane-based technology has been evaluated at the meso level by linking the company's process with Stena Recycling, which charges the Tuve site for WWT services. For the meso-level eco-efficiency assessment, indicators have been selected and elaborated as follows.

Economic assessment

TVA is generally the water-service value minus various costs – of investment, annual operation, maintenance, inputs and WWT – across the meso-level system. The water-service value would remain the same with the silane-based option, assuming that trucks would have the same product quality and thus the same economic value as before (EcoWater D4.2). Silane-based technology could use the same infrastructure (baths and pipes) as the current process; the different chemical inputs have costs comparable with the current chemicals.

Stena Recycling's charges for WWT depend on wastewater quantity and composition, sludge-disposal costs and energy costs; data for the baseline situation came from Stena and from the LCA database Ecoinvent. The silane-based option would reduce water use, as well as the wastewater quantity and emissions content. The lower quantity would save WWT costs for the Tuve site – and thus reduce such income for Stena. There is no information (and thus uncertainty) about whether the lower-emission content would lower the unit fee for WWT. The water-supply company too would lose some income. The total costs of water-related inputs would be somewhat reduced for all three companies (Volvo, its water supplier and WWT) because the lower quantity of both water use and WWT means a lower electricity demand for pumps and less use of chemicals. On the above assumptions about the silane-based option, the TVA slightly rises through lower costs for water input.

More significantly, based on the above calculations, the TVA would be redistributed across the meso-level value chain. The Tuve site would pay the water-supply company for less water and would pay Stena for less wastewater to treat. Table 1 helps to visualise qualitatively the distributional effects among actors across the meso-level value chain. Less important than calculations, the distributional issues highlight the importance of stakeholder discussions on eco-efficiency improvements before any investment decisions; the table facilitated such discussions.

Table 1 | Distribution of economic and environmental changes in the silane-based option

UMEVA: water supply	Kretslopp & Vatten: water supply	Volvo trucks: water supply, use and WWT	Stena recycling: WWT	Eco-efficiency of total value chain
Econ. = Environ. =	Econ. – Environ. +	Econ. + Environ. +	Econ. – Environ. +	Increase

Environmental assessment

Indicators follow the standard midpoint impact categories (JRC 2011) (see 'Methods and research focus' section above); for climate change, the main parameter was CO_2 emissions from production of the electricity used. Based on Volvo Trucks' tests, Figure 2 compares the silane-based option (diamond-shaped nodes) with the baseline situation (circle-shaped nodes); the former offers environmental improvements through several parameters, that is, specific components or contributors to the above environmental indicators.

Multi-stakeholder involvement

The EcoWater project held a Gothenburg workshop which brought together representatives from the main actors: Volvo Technology (VTEC), Volvo Trucks, Stena Recycling (the latter's contractor for WWT) and the Swedish Agency for Marine and Water Management (HaV). In a presentation VTEC staff described the company's holistic view of resources, emissions, quality, and safety. It attempts to 'avoid–reduce–recycle' waste. Closed-loop systems have several advantages in cost-savings, resource recycling and product quality (Lindskog 2013). According to the VTEC speaker, as summarised in the workshop report:

> 'Water and energy demands at the Umeå production site depend partly on the scheduling between the different steps of the anti-corrosion surface treatment process, while water use efficiency depends on the overall process design and the selected technologies … The largest water consumption is associated with the pre-treatment step (metal surface treatment before painting, including degreasing and methods for corrosion protection), and the painting processes which use liquid coatings' (EcoWater 2013: 33–34).

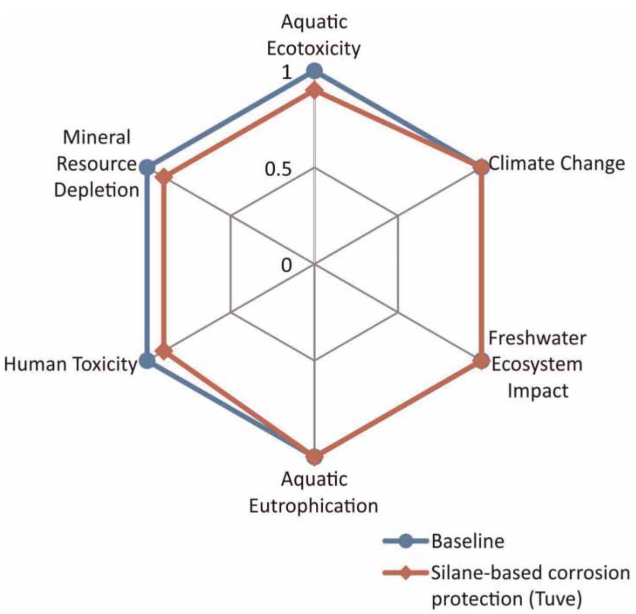

Figure 2 | Silane-based option compared with environmental baseline (phosphating technique).

As Volvo's conduit for WWT, Stena described relationships between the two companies:

> 'Volvo provides information on the generated wastewater thus simplifying the treatment processes, while Stena Recycling informs Volvo concerning the quality of the received wastewater, thus providing feedback on the production processes. If Volvo improved its environmental performance and generated effluents of better quality, it would be easier for Stena Recycling to comply with the regulations. Highly polluted effluents increase the cost of the treatment process. The set-up of business agreements with Volvo, which would benefit both sides, can be enhanced by working more closely together as part of a common system – for example, variable rate, flat rate, fee for extra pollution' (EcoWater 2013: 35–36).

An EcoWater presentation compared the eco-efficiency of silane technology with the baseline scenario (as in Figure 1 above). According to Volvo, this technology would have several advantages, allowing 'lower resource consumption and less waste', if the technology is shown to provide sufficient protection (Lindskog 2013). Volvo is putting its trucks through a field test for several years before proper evaluation can be made; if the corrosion-protection is proven adequate, then costs are already known.

Some important conclusions of the workshop are as follows (EcoWater 2013: 37–38):

> 'The proposed silane-based technology can improve eco-efficiency of the Volvo Trucks water system.'

> 'Water recycling is a promising option for improving the performance of water-consuming production processes.'

> 'Technologies should be selected for improving the whole system, not only in the specific processes where they are implemented, in order to avoid sub-optimisation.'

> 'Sub-optimisation can be more easily avoided through stakeholder cooperation in evaluating the overall

system. Organisation of the different "players" towards a common goal can increase cooperation among actors that perhaps unknowingly share a mutual interest in environmental protection.'

Thus both major stakeholders showed interest in the meso-level analysis of options for improving the system under study.

ARLA DAIRIES: WASTEWATER PRE-TREATMENT OPTION

Arla Dairies have been adopting or considering major changes in the production process. Impetus has come from the company's ambitious expansion plans, its interest to protect farm-gate milk prices, and its environmental targets aimed at consumers. Arla Dairies own approximately 40% of dairies in Denmark and many abroad, especially resulting from an expansion policy (Arla Foods 2013: 2). EU milk quotas may be relaxed, thus increasing the supply, yet extra milk products cannot be sold on a static European market. Given those limits, Arla's expansion aims to export high-quality or specialty milk powder. But its production requires enormous extraction of water and thus energy inputs.

Arla plants have already adopted resource-efficiency measures, for example, cleaning-in-place systems to minimise water use and effluent. There is a substantial transfer of milk ingredients, including large amounts of water, among dairies in the Arla Group through lorries. Water extracted from milk is reused in rinsing casein protein. Its milk powder plants obtain substantial electricity from biogas produced from Arla's wastewater sludge as well as from local manure.

Such innovations have been driven by several factors – the aim to maximise the market value of the farmers' milk, the company's reputation among consumers, cost-saving and environmental taxes; the company also anticipates scarcer water and higher costs in the future. Such drivers have converged in the company's decisions on innovation investment (Nørgaard 2013). Owned by farmers and accountable to their representatives, Arla aims to counter the recent trend towards lower farm-gate milk prices: 'During spring 2012 Arla introduced a series of cost-saving measures in order to drive efficiencies throughout the company and create the potential to raise the milk price' (Arla Foods 2013: 3).

Such innovations have been driven by the company's efforts at milk-price maintenance, cost-saving and its consumer reputation. Since at least 2008 Arla Foods has promoted its overall policy direction as 'Closer to Nature', emphasising its commitment to environmentally sustainable methods. Its Environmental Strategy 2020 includes various targets for resource conservation, for example, reducing greenhouse gas (GHG) emissions by 25% in production and transport, and reducing energy and water consumption in production by 3% every year (Arla Foods 2011).

Those sustainability targets have become performance targets, to be implemented by each dairy plant in the economically best way. So environmental and economic aspects are indirectly combined in investment decisions. Arla Dairies have specialist teams which have already developed previous innovative practices. But there has been no systematic discussion with external actors across the water-service value chain for comparing options.

Arla have been evaluating options for investing in its own expensive technology. Two possible options are to remove water more extensively from process water (e.g. through advanced membrane technologies) or to do pre-treatment of its wastewater. The EcoWater case study initially focuses on Arla's Holstebro HOCO plant, which processes milk into powder. It has been paying a specialist company for WWT. HOCO is considering several in-house options to reduce demand for water and energy.

Eco-efficiency comparison: wastewater pre-treatment option

One such option is in-house anaerobic wastewater pre-treatment. Potential changes in eco-efficiency have been evaluated with the following indicators.

Economic analysis

Indicators are freshwater abstracted and process energy (electricity costs), chemical-input costs, WWT costs (internal or external). The savings in external payments for WWT would be significantly countered by the extra investment cost. So the TVA shows only a small increase over the baseline scenario (Andersen 2013).

Environmental analysis

Indicators follow the midpoint impact categories (JRC 2011) (see 'Methods and research focus' section above). For a meso-level eco-efficiency analysis, the EcoWater study drew on information from Arla and water companies. Based on that information, the above option would have the following changes in resource usage and burdens (Andersen 2013):

- Production of biogas to substitute natural gas → reduced fossil fuel depletion and CO_2 emissions.

- Reduced load on WWT plant → reduced power consumption and CO_2 emissions.
- Reduced biogas production → reduced downstream power and heat production.

Regarding the latter point, in-house anaerobic pre-treatment would reduce the WWT plant supply of biogas to district heating, which then would need more fossil fuels; the overall result would be a small reduction in fossil fuels and GHG emissions relative to the baseline scenario, as shown in the spider diagram (Figure 3).

Figure 3 compares the in-house WWT option (diamond-shaped nodes) with the baseline situation (circle-shaped nodes). So the former offers minimal eco-efficiency benefits from a whole-system value-chain perspective. By contrast, a micro-level focus on Arla's internal process would deceptively anticipate significant improvement.

Multi-stakeholder involvement

The EcoWater project's Arla HOCO workshop started with presentations on the company's approach to resource efficiency, especially its internal targets (Nørgaard 2013). Within its 'Closer to Nature' perspective, Arla Dairies 'want to appear as a sustainable and responsible company in balance with our surroundings'. This includes specific aims, for example (Hansesgaard 2013):

> 'We strive for a CO_2-neutral energy source in 2015 by entering a supplier agreement with Måbjerg Bioenergy [producing biogas from Arla's sludge].'

> 'We aim at a "natural" milk protein ingredient through development of a new casein process avoiding use of acid/hydroxides.'

> 'Reduction of use of energy, water and chemicals as well as amount of waste water by 25% per kg powder (2011–2014) through optimisation and development of processes.'

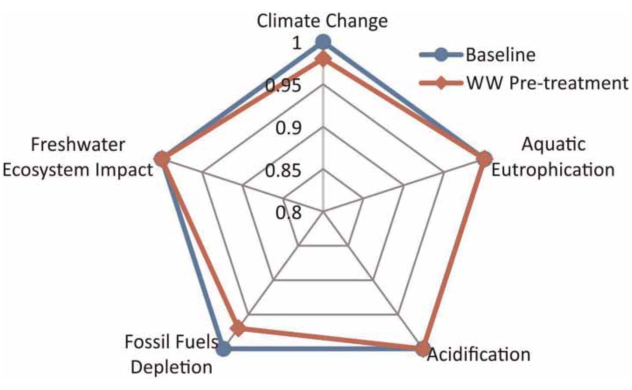

Figure 3 | Wastewater pre-treatment option compared with environmental baseline.

The case-study team presented its whole-system value-chain assessment of in-house wastewater pre-treatment, which would offer minimal benefits (Andersen 2013; Figure 3 above). In response, Arla representatives saw the EcoWater eco-efficiency assessment method as helpful for considering whole-system effects. They expressed interest in several follow-up steps, for example, applying the eco-efficiency assessment method jointly with the WWT company to other innovative options, and applying the method to a milk-producing dairy plant.

DISCUSSION AND CONCLUSION

The well-known eco-efficiency concept helps to assess the economic value and resource burdens of potential improvements by comparison with the baseline situation. But such evaluation has generally focused on specific production sites, while neglecting wider effects through interactions; this micro-focus may reinforce sub-optimal solutions and neglect better innovative opportunities. Meanwhile macro-level studies have quantified wider changes, for example, in an entire industrial sector or region, but cannot identify what processes generated them (see 'Introduction' for references).

To fill the knowledge gap, the EcoWater project has developed a method and online tools for meso-level analysis of the entire water-service value chain. The meso level encompasses interactions among heterogeneous actors (cf. Schenk *et al.* 2007) – especially water users, providers and WWT companies. This study investigated innovative options in two large manufacturing companies, Volvo and Arla, which have already made substantial investments in resource efficiency. They have significant potential for further improvements in the water-use process. They have been considering investment in extra processes which can lower resource burdens from inputs and wastewater, as well as for internalising WWT processes. In both case studies, impetus comes from companies' environmental policies, as well as from external drivers such as future higher costs and resource scarcity, beyond legislative requirements.

In developing its methodology, the EcoWater project obtained the necessary information from many agents (cf. Reid & Miedzinski 2008: 22), involved them in the meso-level assessment and facilitated their discussion on alternative options for whole-system improvement. Each case study combined the necessary information from relevant stakeholders and LCA databases, as a knowledge-basis for comparing specific alternative options with the baseline situation. Stakeholders showed interest in the eco-efficiency calculations, although their wider significance lies in the overall method and tools for comparing options. For one option, the meso-level assessment method revealed minimal improvement in eco-efficiency, while a micro-level assessment would deceptively anticipate significant improvement. In such ways, the comparative method can help stakeholders jointly choose or create better solutions.

Cooperation with the EcoWater study stimulated internal company discussions on the need and means to evaluate whole-system effects of investment decisions. Such discussions with stakeholders stimulated their attendance at a workshop to discuss innovative options and the meso-level eco-efficiency assessment for comparing them. For such a whole-system analysis, stakeholders expressed interest in jointly extending the EcoWater method to more options and in discussing investment strategies.

Given the difficult link between micro-level and macro-level eco-efficiency (Huppes & Ishikawa 2009: 1698), the EcoWater method highlights causal links at the meso level. The method can facilitate decisions towards better whole-system solutions. Progress will depend on stakeholders overcoming fragmentation by sharing responsibility and knowledge.

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