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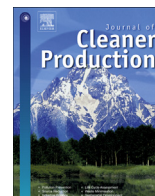
# Process eco-innovation: assessing meso-level eco-efficiency in industrial water-service systems

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## ABSTRACT

Eco-innovation combines economic advantage with lower ecological-resource burdens. Eco-innovation has been generally directed at energy input-substitutes, component recycling, etc. Some companies have made investments reducing resource burdens in the production process. This study investigated options for eco-efficiency improvement in two large manufacturing companies, Volvo and Arla Foods. Their impetus for eco-innovation comes from the companies' environmental policies, as well as from external drivers such as future higher costs and resource scarcity. Relative to their respective industrial sector, these companies represent strong prospects for reducing resource burdens in water-service processes, especially from chemical inputs and wastewater. Such eco-innovations involve more complex interactions beyond the production site, so the options warrant a whole-system comparative assessment.

The EcoWater project has analysed the entire water-service value chain through meso-level interactions among heterogeneous actors (process-water users, providers and wastewater treatment companies). The project has developed a methodology to obtain the necessary information, to involve stakeholders in the assessment and to facilitate their discussion on alternative options. Each study stimulated internal company discussions on the need and means to evaluate whole-system effects of investment decisions. Inter-organisational cooperation helped to anticipate how meso-level resource-efficiency relates to lower burdens in wastewater treatment.

The assessment method can be extended to any water-service system. By comparing options, the method can facilitate better decisions improving meso-level resource efficiency. As wider implications, some improvement options may complicate 'eco-innovation' as double-eco benefits: win–win for whom, where and what level?

## 1. Introduction: meso-level eco-efficiency

Eco-innovation encompasses various innovative practices combining economic and ecological-resource benefits. Commonplace examples have been renewable energy or (more recently) biomass as an input-substitute for fossil fuels. Going further, production-process upgrading has lowered resource burdens, e.g. by substituting less harmful chemical inputs, internally treating wastewater, reusing water and/or wastes, etc. Such improvements generate relatively greater changes beyond a specific production site, e.g. through its relation with a wastewater treatment plant.

To evaluate such improvement options, eco-efficiency denotes a ratio between economic benefits and ecological-resource burdens. This ratio helps to compare any current or future changes with a baseline. Eco-efficiency has been generally assessed in a micro-level system, e.g. at a specific site in a company's production processes. This focus neglects wider effects, warranting assessment at

the *meso-level*, which has also been called the whole system. Some experts and practitioners have emphasised the need for such an assessment, encompassing the entire value chain of a production process, alongside shared responsibility for whole-system improvement. From an inter-organisational perspective, the whole-system or meso level can be defined as interactions among heterogeneous actors across the entire value chain (see Methods section).

This paper addresses two main questions:

- For whole-system effects on eco-efficiency, what methods can assess and compare eco-innovations?
- What is the role of inter-organisational cooperation in such comparisons?

These questions will be addressed through preliminary results of the EcoWater research project. As a literature survey, Section 2 explains the concepts of eco-innovation and its eco-efficiency assessment, as subsequently integrated in Section 3 on research methods. Then Sections 4 and 5 show how the project applied those methods and concepts in two case studies. On that basis, the conclusion answers the above question and suggests wider relevance.

## 2. Eco-efficiency through eco-innovation: analytical concepts

This section links analytical perspectives on eco-innovation and eco-efficiency, as a basis for the methodological novelty presented in the subsequent section on Methods.

### 2.1. Eco-innovation: forms and options

Eco-innovation encompasses various innovative practices which enhance resource efficiency by combining economic value with environmental performance (see Fig. 1). By combining such benefits, it has been widely seen as 'enabling win—win synergies' (OECD, 2012). But motives may be diverse and ambiguous. Cases can be distinguished 'where environmental motives are as important as (or less important than) economic motives'. Where the latter are most important, environmental improvements can be unintentional effects of investment decisions (Markusson, 2011: 300). Primarily economic motives may stimulate resource-efficiency improvements which incidentally reduce emissions (Clayton et al., 1999).
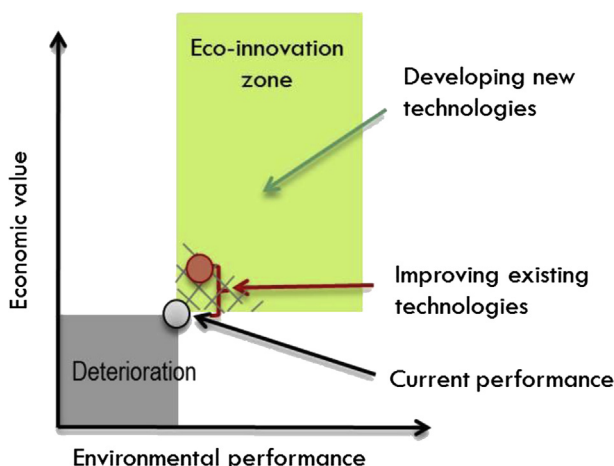


**Fig. 1.** Eco-innovation through new technologies (Credit: IVL).

Giving 'eco' a double meaning, eco-innovation has been defined more broadly as 'a change in economic activities that improves both the economic performance and the environmental performance of society' (Huppes et al., 2008: 29). According to the Europe INNOVA Panel on Eco-innovation:

Eco-innovation means the creation of novel and competitively priced goods, processes, systems, services, and procedures that can satisfy human needs and bring quality of life to all people with a life-cycle-wide minimal use of natural resources (material including energy carriers, and surface area) per unit output, and a minimal release of toxic substances (quoted in Reid and Miedzinski, 2008: i).

According to most definitions, eco-innovation reduces the environmental impact caused by consumption and production activities, regardless of whether this is the main motivation. Taking many forms, eco-innovation varies from incremental eco-efficiency improvements to fundamental change replacing a system (Carrillo-Hermosilla et al., 2010: 1073–74). Towards the latter improvements, the European Commission has promoted an Integrated Product Policy, aiming to support the realisation of environmental product innovations which broadly reduce all environmental impacts throughout a product's life cycle. This has been conceptualized as 'integrated environmental product innovation' (Triebswetter and Wackerbauer, 2008). Innovation has several roles in resource efficiency (EIO, 2011b: 12).

Manufacturing industry has introduced such innovations, e.g. through water-efficient technologies reducing water demand and pollution. A closed-cycle process 'maximises the useful life of products and minimises the waste and loss of valuable and scarce metals' (Ayres and van der Lugt, 2011). Eco-innovation has been 'closing the loop' between water and energy management in a Cleaner Production perspective, e.g. through WW reuse: 'once-through cooling, where the water is used once for cooling and then directly is discharged, is replaced by closed-loop systems and cleaning-in-place (CIP) systems, where cascading is part of the cleaning process' (WssTP, 2013: 41).

Eco-innovation depends on parallel socio-institutional innovation, as academic studies have emphasised (Rennings, 2000). Accordingly, eco-innovation is understood more broadly than technologies:

The scope of eco-innovation may go beyond the conventional organisational boundaries of the innovating organisation and involve broader social arrangements that trigger changes in existing socio-cultural norms and institutional structures (OECD, 2009: 2).

Eco-innovation is influenced by interactions among regulators, firms and other actors. Understanding such interactions is essential for facilitating eco-innovation (Del Río et al., 2010: 552). Indeed, inter-organisational cooperation can facilitate assessment of improvement options, as discussed next.

### 2.2. Eco-efficiency assessment: meso-level novelty

Various eco-innovations can be compared by assessing their relative eco-efficiency. 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 and Gee, 1999: 24). To be operationalized, the concept denotes a quantifiable ratio between the economic value and resource burdens of a process (e.g. Seppala et al., 2005).

In this way, it means the efficiency of economic activities in generating added value from resources usage, including waste emissions (UNESCAP, 2009: 1).

Although eco-efficiency assessments are sometimes regarded as 'green-washing', recent guidance internationally harmonizes the assessment, thus making it more transparent and credible (ISO, 2012). According to the leader of an international team of experts, Bengt Steen,

> The goal of eco-efficiency assessment is to optimize the performance value of the product system, for example, its resource, production, delivery or use efficiency, or a combination of these. The value may be expressed in monetary terms or other value aspects. The result: doing more with less (ISO, 2012).

Improvement need not mean an increase in production. Beyond the resource-saving efforts of European companies ('achieving more with less'), more radical innovations are needed: 'we must do better with less' (EIO, 2011a: xii). The latter can mean a qualitatively better and/or economically more valuable product, not simply an increase in the same production as before.

Eco-efficiency has been generally assessed at the micro level, e.g. at a specific site in a company's production processes (e.g. Michelsen et al., 2006; van Caneghem et al., 2010). Improving micro-level eco-efficiency may not enhance sustainability and may even increase resource burdens (e.g. UNEP, 2013: 13). A micro-level focus neglects wider external effects, especially through interactions between water suppliers, water users and wastewater treatment providers.

By contrast, macro-level studies have quantified wider changes in an entire industrial sector or region (e.g. Hoffrén, 2001; Jollands et al., 2004; Seppala et al., 2005; Wursthorn et al., 2011), but cannot identify which 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 and Ishikawa, 2009: 1698).

As another limitation, eco-efficiency assessments often neglect wider economic aspects, especially changes in value chains (VCs).

> Conversely, business studies lack the more comprehensive analysis of VCs which extend the focus to external stakeholders, including customers and suppliers other than regulators,

demonstrated to be, in many contributions, the key players in encouraging environmental strategies … the point is to understand how firms may reduce the impact of all the activities performed to realize their products, including those of suppliers and sub-suppliers, therefore moving the focus from firm-level strategies to VC-level strategies (De Marchi et al., 2013: 64).

These difficult links have 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 Fig. 2 below. 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 and Miedzinski, 2008: 22).

As a ratio, 'eco-efficiency' implies that economic and environmental aspects will (or at least should) be considered together in organisational decisions. However, responsibilities may be fragmented across a water-service value chain, even within the same organisation. Better decision-making needs cooperation among all such agents across many sites. Optimal eco-efficiency improvements depend on shared responsibility among stakeholders across the value chain, according to the World Business Council for Sustainable Development:

> Business undoubtedly has many opportunities to increase its eco-efficient performance and thereby to help de-couple use of nature from overall economic growth … 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 (WBCSD, 2000: 6–7).

Multi-stakeholder responsibility depends on broadening assessments, as elaborated in the next section.

## 3. Methods and research focus

An EU-funded research project, EcoWater, has developed a conceptual framework and methodology for assessing eco-efficiency on the meso level. This level is defined as interactions
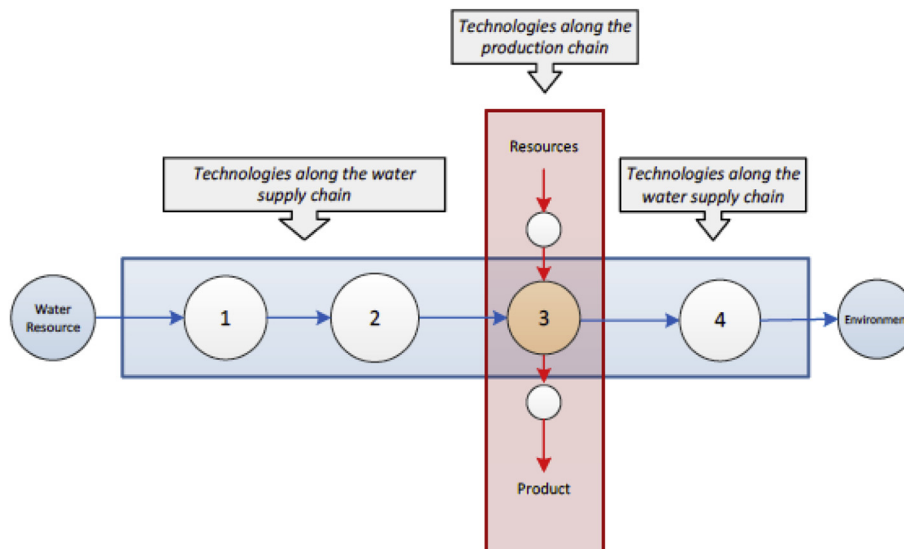


Fig. 2. Stages along the meso-level water-service and production chains (EcoWater, 2013a).

and interdependencies among heterogeneous actors across the entire value chain, linking the water-service and production chains (EcoWater, 2012a; see Fig. 2). The project compares options for innovative practices, including technology adoption, within a specific water-service system, which denotes:

a system which includes the entire range of water services required to render water suitable for a specific water-use purpose, and safely discharging it to the water environment; this system also includes water-using processes and economic activities (EcoWater, 2012b: 45).

Such uses include drinking, cooling, industrial processing, irrigation, etc. 'Water-service system' overlaps with the 'process water' concept from the chemical industry: 'In many cases, water is specifically treated to produce the quality of water needed for the process' (Chemwater, 2013: 13).

Thus a methodological novelty lies in a whole-system (meso-level) eco-efficiency assessment of a water-service system. By operationalizing 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, and thus to inform policy frameworks which could facilitate decisions towards greater eco-efficiency. To explore those issues, several case studies investigate key actors' perspectives through interviews and workshops.

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

- Water or production chain, as shown in Fig. 2: An innovation can upgrade the water-service chain, e.g. the water supply or sewerage system, at stages in the horizontal axis. Or it can upgrade the production chain — e.g. through lower resource-inputs, lower emissions (to water, air or soil) or less harmful by-products — at stages in the vertical axis. In the diagram, 'technologies' is short-hand for innovative practices which depend on more than technologies.
- Process or product upgrading: Within the production chain, process upgrading uses resources in more efficient ways, while production-chain upgrading increases the market value of products.

Such improvements can have synergies. For example process upgrading can reduce emissions in wastewater, in turn facilitating improvements in the water-supply chain, e.g. through in-house wastewater treatment (henceforth abbreviated as WWT), reuse, recycling, etc.

Eco-efficiency is usually calculated as a ratio: total value-added (income minus costs) is divided by resource burdens from inputs and emissions. A baseline eco-efficiency assessment identified the processes or sites which have the greatest resource burdens in each case study, e.g. in a production plant. These sites became the focus for comparing improvement options with the baseline situation and with each other.

Defined as interdependencies among heterogeneous actors, the meso level lies at the nexus between two value chains and their actors:

- the product value chain (Fig. 3, vertical sequence), including resource inputs, potential reuse of emissions or energy; and
- the water-service value chain (horizontal sequence), including water supply, WW emissions, WWT, WW reuse, etc.

The diagram indicates relations among actors who are directly involved in the water-service value chain:

Directly involved actors, referring to the organizations and/or individuals that manage the corresponding stages (or elements), have direct economic benefits and costs, and take decisions. Directly involved actors are the main source of the required information on economic and environmental performance (EcoWater, 2012b: 14).

Those actors had priority for research interviews, which explored improvement options, responsibility for them, relations with other actors, etc. Indirectly involved actors, e.g. government departments and regulatory authorities, may influence decisions by the directly involved ones. All those actors were invited to attend workshops; most did so.

As a factor in selecting companies as case studies, they already made significant investment in eco-innovation, were considering further improvements in process upgrading and showed interest in cooperating with the project. Each case study initially mapped the meso-level value chain in order to identify the flow of resources and money amongst interdependent actors. Each case study also identified the processes which incur the greatest resource burdens and water-based emissions, seen as the environmentally weakest stages, e.g. from a production process to a WWT plant. This modest study selected one or two WW sources as the focus for options
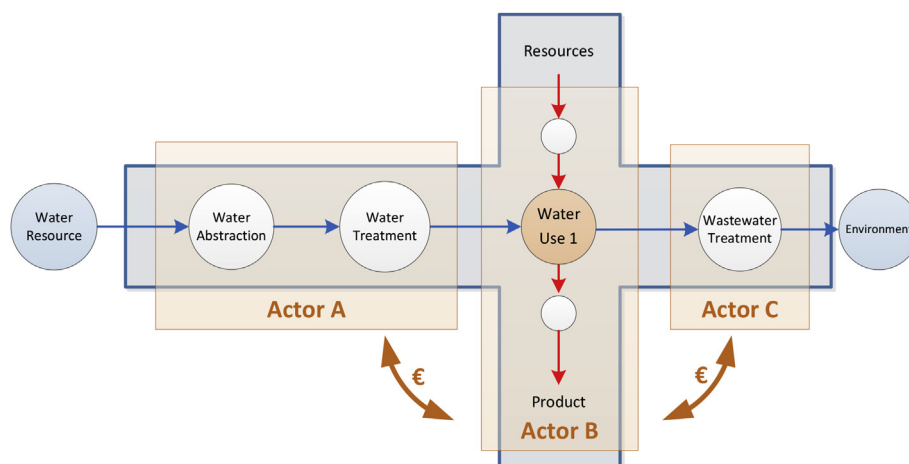


**Fig. 3.** Economic and resource flows in the meso-level water-service system (EcoWater, 2013a).

which could improve eco-efficiency. From discussions with the company, each case-study team initially focused on one or two improvement options to adapt and refine the eco-efficiency assessment method, especially in preparing the first multi-stakeholder workshop.

An eco-efficiency ratio has two main components, each with its own indicators:

- Economic indicators: Total Value Added (TVA) by the water-service system and related production process in the value chain. 'Total' denotes the economic value minus various costs of inputs, water abstraction, treatment, WWT, etc.
- Environmental indicators: a standard set of midpoint impact categories, e.g. climate change, ozone depletion, eutrophication, human toxicity, eco-toxicity, acidification, resource depletion, etc. (JRC, 2011). For each case study, data were collected on the most important environmental parameters (e.g. material inputs, energy inputs and their source, pollutants, etc.) and were converted into the JRC mid-point indicators. Impacts were adjusted to each context; for example, water abstraction per se has a relatively lower 'freshwater ecosystem impact' in a water-abundant context.

For each case study, both indicators encompass potential changes and their effects at multiple sites in a value chain. Data came mainly from company sources where available and otherwise from LCA documents (EcoWater, 2012a). Each production site was the focus for comparing improvement options with the baseline situation and with each other. Results were depicted in spider-type diagrams, comparing the resource burdens of each option with the baseline situation (e.g. Figs. 5 and 6).

A meso-level assessment has different boundaries than methods which encompass all stages of a product's origin and fate. In particular, green supply-chain management means 'integrating environmental thinking into supply chain management, including product design, material sourcing and selection, manufacturing process, delivery of the final product to the consumers as well as end-of-life management of the product after its useful life' (Srivastava, 2007: 55). LCA likewise encompasses product use and disposal.

By contrast to a product focus, a meso-level eco-efficiency assessment compares options for upgrading a production process and/or a product's value through interactions among heterogeneous actors. More specifically, the EcoWater method assesses the value added by the water-service role, divided by all its resource burdens, e.g. of producing inputs and treating effluents. The meso-level assessment generally excludes product use and disposal, whose effects lie beyond potential improvements in or from the water-service value chain. An exception is an urban water-supply system, where the water itself is the main product; its disposal via wastewater and thus the resource burdens could be changed by earlier stages (e.g., Ribarova et al., 2014, also from the EcoWater project).

A related methodological issue, which could be either a limitation or a flexible advantage, is where to set the meso-level (whole-system) boundary; this was not initially obvious. The boundary judgement depends partly on the resource burdens being prioritised, the improvement options being assessed and their interactions with a wider value chain, as in the case studies below. Where a motor vehicle's cabin is transferred across sites in a production process, a broad system boundary helps to compare improvement options at both sites and to identify any interactive changes in resource burdens (Fig. 4 below; EcoWater, 2014a: 39). Dairies depend on a large transport of milk, milk powder and other milk ingredients by other companies, so a broad system boundary helps to identify options to reduce such transport and its resource burdens (EcoWater, 2014a: 29). Such boundary judgements relate to how eco-innovation potentially improves a meso-level system.

Another methodological issue has been how to obtain adequate, relevant data. Its availability has sometimes guided the choice of a specific site for a case 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, so this poses a methodological limitation. By estimating the range of uncertainty for indicators, the assessment can know whether or how uncertainty affects the comparison of technology options – the main aim.

To explore the above issues, this paper draws on two case studies of manufacturing processes – Volvo Trucks and Arla Foods. Each has internal drivers beyond any regulatory requirements. Relative to its wider industrial sector, each company represents strong prospects for eco-innovation in water-service processes.

Each case will be presented along the following lines:

- the sector-wide context for the company's eco-innovation agenda;
- the company's internal drivers and responsibilities for linking economic value with lower resource burdens;
- the company's eco-innovation already adopted or being considered;
- meso-level eco-efficiency assessment of one option as a methodological example;
- multi-stakeholder involvement in evaluating options.

Let us examine the above aspects of our two case studies in turn.
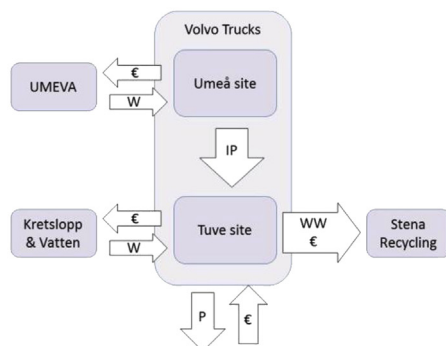


Transactions between actors
€ = economic
W = water
WW = wastewater
IP = internal product (truck cabins)
P = product

**Fig. 4.** Meso-level water-service system across two Volvo plants Credit: IVL, Goteborg.
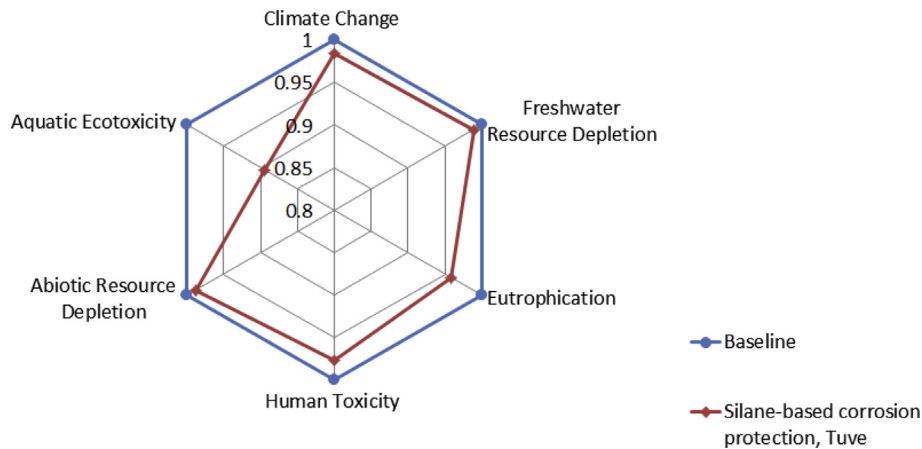
**Fig. 5.** Silane-based option compared with environmental baseline (phosphating technique). Credit: IVL, Goteborg.

## 4. Volvo Trucks

Relative to the overall automobile sector, the Volvo Group has gone further in adopting and considering improvements within the production process. Such changes would affect a plant's relation with the WWT provider, with overall implications and uncertainties about eco-efficiency. Such potential changes interested all stakeholders in the EcoWater assessment of meso-level eco-efficiency, as explained in this section.

### 4.1. Sector-wide context for eco-innovation

The automobile sector has generally directed eco-innovation at vehicle use and users, especially greater fuel efficiency as a competitive advantage, as well as $CO_2$ reductions as a regulatory criterion (e.g. Oltra and Maïder, 2009). The sector has incrementally improved the energy efficiency of the internal combustion engine. Since the 1990s some manufacturers have also developed alternative-fuel vehicles (Sierzchula et al., 2012; Köhler et al., 2013). For example Volvo and Ford developed bi-fuel vehicles flexibly accommodating both methane and petrol: 'Instead of challenging the part of the technological paradigm they controlled themselves, Ford and Volvo thus chose solutions challenging other actors in the technological paradigm such as the fuel infrastructure and consumers' (Williander, 2007: 207). The Renault–Nissan Alliance seeks to develop market leadership in zero-emission electric vehicles (Banu et al., 2012: 298–99).

Why the emphasis on vehicle use rather than its production process? In the EU context a key driver has been legislation requiring that by 2015 $CO_2$ emissions from all new EU-registered cars should not exceed an average of 130 g $CO_2$/km across the range of each manufacturer; this limit was around one fifth below 2007 levels (EC, 2009). Moreover, car manufacturers receive official recognition and carbon credits if they fit their new cars with approved 'eco-innovations' (EC, 2011). The entire list pertains to automobile use, not its manufacturing process.

Given those market and legislative drivers, redesign has sought to reduce energy usage and its $CO_2$ emissions in vehicle usage. According to the European Automobile Manufacturers Association, the industry has been developing several eco-innovative types of vehicle technologies, e.g. adaptive cruise-control, super-efficient LED lights, robotized gearboxes and heat storage and re-use (Business News, 2011). For example the BMW Group has improved fuel efficiency through better energy management, e.g. through an 'auto start-stop' function. In addition, Michelin has developed energy-saving tyres. Audi has developed an energy-efficient LED lighting system; in 2013 it became the first car manufacturer to receive an eco-innovation certification from the European Commission.

Going beyond product use, some automobile companies have also developed eco-innovation at manufacturing sites. Towards
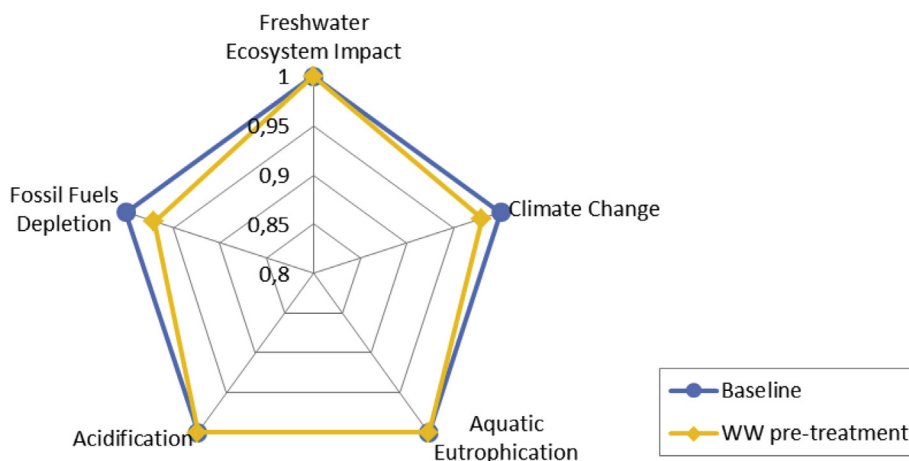


**Fig. 6.** WW pre-treatment option compared with environmental baseline Credit: DHI, Copenhagen.

'sustainable plants', Toyota has sought to reduce $CO_2$ emissions, e.g. through photo-voltaic power generation systems substituting for fossil fuels. Outside plants it covers walls and roofs with vegetation that can help to absorb emissions of nitrogen oxides and to apply photo-catalytic paint which can break down airborne NOx and sulphur oxides (METI & OECD, 2010: 62). Even at production sites, then, companies' environmental initiatives emphasise energy substitutes and the plant exterior rather than the internal production process. Volvo Trucks in Ghent was the world's first $CO_2$-neutral plant (Volvo, 2008).

As another process for eco-innovation, recycling component materials can increase income (Dobers and Wolff, 1999: 38). The Renault–SITA joint venture aims at increasing the reuse rate for products and raw materials in current processes and at developing new processes, especially for recycling materials in end-of-life vehicles. More recently, component recycling has been facilitated by input substitutes, such as bio-based materials at Ford (Cowan, 2009; Howard, 2011). One driver has been the rising cost of primary commodity prices (Banu et al., 2012: 298–99). As a stimulus to redesign components for recycling, the EU's 2000 End of Life Vehicles Directive (ELVD) aims to prevent waste generated by vehicles which have less than 3.5 tons total weight; it requires the reuse, recycling and recovery of end-of-life vehicles and their components.

While product innovations often add end-of-pipe devices for pollution control, 'environmental product innovations' reduce or avoid resource burdens in the production process. The latter type can eventually reduce costs but require long-term investment (Rennings, 2000). In the short term, process redesign loses sunk investments in automobile production systems (Orsato and Wells, 2007).

In the automotive industry, integrated environmental product innovation is driven by several factors – e.g., regulatory pressures, the search for competitive advantage and technological lead, as well as customer pressure; regulatory pressures include sector policies such as emission standards and wider non-sector energy conservation issues, at both national and international levels. According to a study of the Munich automotive industry, such innovations include: design for component recycling in a car manufacturing company, the common rail diesel engine in a commercial vehicle company, the development of an oil-free piston compressor and a pneumatic derailment detector in a railway vehicle company. When innovations are driven by regulatory pressure, they generate similar competitiveness advantages as innovations undertaken voluntarily by companies. Such results yield supporting evidence for the 'Porter hypothesis', whereby environmental legislation stimulates innovation which can simultaneously reduce pollution and increase productivity (Triebswetter and Wackerbauer, 2008).

### 4.2. Volvo's eco-innovation initiatives

Going beyond many other automotive companies, Volvo's agenda for resource efficiency has driven eco-innovation 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'. Operations attempt to reduce resource burdens, e.g. by minimising inputs and recycling materials.

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).

The company's environmental perspective goes beyond vehicle use:

Our environmental efforts extend not only to the trucks. Manufacturing is an equally important part of a sustainable business. Our overall goal is to keep production imbued with sustainability at all levels, from factory to dealer. … As part of our environmental activities, we focused on constantly improving our production methods, manufacturing plants and transportation to and from our factories to the environment. (http://www.volvotrucks.com/trucks/sweden-market/sv-se/aboutus/environment/Pages/environment.aspx)

The Volvo Group is structured by operations at several sites which are considering various eco-innovations. As shown in Fig. 4, the EcoWater case study investigated production units of Volvo Trucks in Tuve and Umeå, located in southwest (Gothenburg) and northeast Sweden, respectively. The Umeå unit produces truck cabins for the Tuve site. The diagram shows the flows of water and payments, e.g. between each Volvo unit and a water supplier (on the left), and from the Tuve site to Stena for WWT.

Within that sub-system, Volvo has considered several potential improvements, in particular:

Silane-based corrosion protection (see below) has relevance to Volvo Trucks' Tuve site, which produces frame beams and has a vehicle assembly line. Silane-based technology has been used for a few years in other companies' vehicles (Chemetall, 2010), but some silane-based options have limitations, e.g. by depending on the use of hazardous organic-based solvents; or by reacting with organic paints, damaging their integrity and thus undermining corrosion protection (Momentive, 2011). Moreover, the technology would need to achieve better corrosion protection, as shown in field tests, to fulfil the higher-quality criteria of Volvo Trucks.

At each of the two sites, different units have responsibility for economic and environmental evaluation, with some discussion between them, further stimulated by engagement with the EcoWater study. There had been no systematic discussion between Volvo and WWT companies about eco-innovation options. So fragmented responsibilities impede or complicate a whole-system eco-efficiency analysis, as a basis to identify optimal solutions.

### 4.3. Eco-efficiency comparison: silane-based process

The EcoWater study initially focused on improvements in the corrosion-protection process. Volvo Trucks has already made an environmental improvement by replacing Cr(VI) 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 WW, 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 Business As Usual (BAU); water use 50–90% less than BAU; no use of heavy metals or P; no hazardous sludge and very little other sludge. WW pollutants (Zr, silane, fluoride) can be reduced to ~0 mg/l by ion exchange.

A silane-based substitute has been considered at Volvo's Tuve site. Silane-based technology has been evaluated for eco-efficiency at the meso level, i.e. linking both Volvo sites with the wider value chain, by obtaining information from the three relevant companies (see again Fig. 4). Economic and environmental indicators have

been selected and elaborated as follows (for details see EcoWater, 2014b).

### 4.3.1. Economic assessment

TVA is generally the water-service value minus costs of inputs and WWT across the meso-level system. The former 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, 2014a). 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.

WWT costs generally depend on WW composition and quantity, sludge disposal costs and energy costs; data for the baseline context came from the WWT company and from the LCA database Ecoinvent. The silane-based option would reduce water use, as well as the WW quantity and emissions content. The lower quantity would save WWT costs for the Tuve site — and thus lose such income for Stena. There is no information (and thus uncertainty) about whether the lower-emission content would lower Stena's unit fee for WWT.

The total costs of water and water-related inputs would be somewhat reduced for all three companies (Volvo, its water supplier and WWT) because lower-quantity water use and WWT mean 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-inputs.

More significantly, 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 the WWT company Stena for much less WW to treat. Both water-service companies would lose income, especially Stena; each company's change in net economic performance is shown in Table 1 below. These distributional issues highlight the importance of stakeholder discussions on eco-efficiency improvements before any investment decisions.

### 4.3.2. Environmental assessment

For the midpoint impact indicators (JRC, 2011), data came from Volvo Trucks' tests and Open Access data sources. Fig. 5 compares the silane-based option (diamond-shaped nodes) with the baseline situation (circle-shaped nodes); the former offers environmental improvements through several parameters, i.e. specific components or contributors to the above environmental indicators. Improvements appear mainly in aquatic ecotoxicity and eutrophication, due to reduced emissions to water of heavy metals and phosphorus. Although the silane process significantly reduces the water input, the overall improvement appears negligible because the Umeå site uses relatively much more water and the abundant freshwater sources have a low exploitation index.

### 4.4. Volvo workshops

In March 2013 the EcoWater project held a Gothenburg workshop which brought together representatives from the main actors:

**Table 1**
Redistribution of economic value and environmental burdens in the silane-based option.

| | Kretslopp & Vatten: water supply | Volvo Trucks: water supply, use and WWT | Stena Recycling: WWT | Eco-efficiency of total value chain |
|---|---|---|---|---|
| Econ. Δ | Econ. − | Econ. + | Econ. − | Increase |
| Env. Δ | Env. + | Env. + | Env. + | |

Positive signs denote greater economic value or environmental improvement.

Volvo Technology (VTEC), Volvo Trucks, Stena Recycling (the latter's contractor for WWT) and the Swedish Agency for Marine and Water Management (HaV). As reported in a presentation, Volvo Trucks has been adopting or considering various innovative processes within a 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).

The VTEC representative described resource interdependencies among the various stages, 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, 2013b: 33–34).

In the discussion a VTEC participant noted: When evaluating eco-efficiency of a technology, a whole-systems perspective will reduce the risk of sub-optimization.

Stena described the two companies' interdependencies, making cooperation more important:

> 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 — e.g. variable rate, flat rate, fee for extra pollution (EcoWater, 2013b: 35–36).

According to the company, silane-based technology would have several advantages, allowing 'lower resource consumption and less waste', if the technology is shown to protect the truck bodies sufficiently from corrosion (Lindskog, 2013). An EcoWater presentation compared the eco-efficiency of silane technology with the baseline scenario (as in Fig. 5 above).

For the silane-based alternative, workshop comments identified two different uncertainties — about efficacy and regulatory standards. The technology needs to demonstrate adequate efficacy for Volvo Trucks before commercial use. Volvo is putting its trucks through a commercial test for at least two years; if the corrosion-protection is proven adequate, then costs are already known. The relevant Bref document compares Cr(VI) with phosphating techniques; it briefly mentions silane-based alternatives, without an evaluation regarding BAT standards (CEC, 2006). As this gap illustrates, companies face uncertainty about whether the authorities will accept such alternative as 'best available' technology. Although BAT standards have provided a common minimum, future uncertainty potentially serves as a limit of eco-innovation.

Workshop conclusions emphasised the need for multi-stakeholder cooperation to optimise whole-system improvements. In particular:

> 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.

Case-specific indicators that take into account the potential drawbacks from adopting new technologies should be considered in the analysis. This is to avoid introducing a problem that did not exist in the initial technology and so lay outside the baseline evaluation.

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. Organization of the different 'players' towards a common goal can increase cooperation among actors that perhaps unknowingly share a mutual interest in environmental protection (EcoWater, 2013: 37–38).

Thus both major stakeholders showed interest in jointly assessing the eco-efficiency of options for improving the meso-level sub-system.

Held in May 2014, a follow-up workshop discussed more improvement options and stakeholder cooperation on investment decisions. The EcoWater case-study team presented spider diagrams of environmental impact and eco-efficiency, showing small improvements in most indicators but also slightly worse result in some indicators, unlike the silane-based option. Stena Recycling asked Volvo for early information about test runs of any new technology and for WW samples, in order to plan well before a change happens (IVL, 2014).

At that workshop an interactive exercise explored barriers and drivers of potential improvements by considering standard categories from scenario-analysis (Van der Heijden, 2005). Among the most important factors, participants identified the following: Economic: electricity price, Environmental: use and regulation of persistent chemicals, Political: policy on scarce resources, especially phosphorous and metals. The exercise anticipated plausible variations in their future trends and how these may drive or impede innovative practices at Volvo Trucks (IVL, 2014). A follow-up exercise could analyse whether each technological option would be robust across the various potential futures.

## 5. Arla Foods

Relative to the overall dairy sector, Arla Foods has gone further in adopting and assessing fundamental improvements in water-based processes, which would also change a plant's relation with the water supply and WWT provider. Such potential changes interested all stakeholders in the EcoWater assessment of meso-level eco-efficiency, as explained in this section.

### 5.1. Sector-wide context for eco-innovation

Dairies have many opportunities for linking economic value with environmental benefits. Initial energy savings have been made with minimal capital investment. Dairies have reduced energy usage for membrane filtration, heating and cooling of products, and spray drying. Greater energy savings may depend on new, more energy-efficient technologies through a process change. Some dairies have been 'reducing the amount of milk that is lost to the effluent stream and reducing the amount of water used for cleaning', as well as reducing chemical usage (COWI, 2000: 28).

Some modest improvements have been stimulated by EU regulations, which give priority to pollution prevention over treatment (EC, 1996). Permits authorise specific technologies and/or

emissions (Honkasalo et al., 2005). In many member states such as Denmark, environmental licences set limits on water use and discharge.

Dairies still have great potential to reuse water, especially from milk, which has a water content of more than 85%. Reuse can be expanded if the water quality can be assured through extra treatment technologies for upgrading rinse-water,, cleaning-in-place (CIP) rinse water, cooling water, pump and separator seal water, condensate, casein wash water and membrane-system permeates (Rad and Lewis, 2014: 5).

The UK dairy and food industries jointly launched a 2008 roadmap to take resource efficiency beyond conventional measures:

> Dairy companies worked with a number of other bodies and sectors throughout 2010 in exploring future technology to reduce further the impact on the environment. One of these initiatives will take dairy processing beyond the traditional carbon management and energy efficiency approach. This will look in detail at production strategies, processes and equipment to identify and implement innovative and novel technologies in dairy processing. (Dairy Supply Chain Forum, 2011: 18).

A report on the Irish dairy industry emphasised reductions in energy use and GHG emissions (Enterprise Ireland, 2011). According to a recent report, Arla took the lead in water-process improvements, i.e. anaerobic digestion of wastewater at some UK plants (Dairy Roadmap, 2013: 49).

### 5.2. Arla's eco-innovation initiatives

As the broader context for eco-innovation, Arla Foods has been undergoing some restructuring, which may result in fewer, larger and more specialised dairies. Greater concentration poses the issue of cleaner production: whether or how the process design could internalise and/or recycle resource-flows among production units. Relative to eco-innovation in the European dairy industry, Arla Foods has already been adopting and considering major changes in the water-service process.

Arla Dairies own approx. 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 find consumers on a static European market. Given those limits, Arla's expansion aims to export high-quality or speciality milk powder. For example, arrangements with China aim to expand markets there: 'The milk powder facility at Vimmerby in Sweden will also be extended to allow for more production to increase export to non-European countries' (Arla Foods, 2013: 2). But powder production requires enormous extraction of water and thus energy inputs.

Arla plants have already adopted resource-efficiency measures, e.g. CIP systems to minimise water use and effluent. Water extracted from milk is reused in rinsing casein protein —and in CIP. Expanding renewable energy sources, 'the milk powder plant in Visby now receives about 40 per cent of its energy as biogas, which is purchased from a unit that generates biogas mainly from manure from farms' (Arla Foods, 2013: 27). Biogas is also produced from Arla's biosolids and from the municipal WW sludge treating the dairy's WW. Lorries transfer large amounts of milk and milk ingredients among Arla Foods dairies, so reducing water content in ingredients would also reduce transport costs and emissions.

Such innovations have been driven by several factors — the company's environmental strategy, the need for cost-efficient production processes and its consumer reputation. Owned by farmers and accountable to their representatives, Arla also aims to

counter the recent trend towards lower farm-gate milk prices (Arla Foods, 2013: 3).

Since at least 2008 Arla Foods has adopted and implemented a strategy, 'Closer to Nature', emphasising its commitment to environmentally sustainable methods. Its Environmental Strategy 2020 sets various targets for resource efficiency and conservation. In particular, the company will reduce GHG emissions by 25% in production and transport by 2020, as well as reducing energy and water use in production processes 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 combined in investment decisions. Arla Foods has specialist teams which already developed previous innovative practices. But there has been little systematic discussion with external actors across the water-service value chain for comparing options.

The EcoWater case study focused on one Arla Foods plant whose products include milk powder. The plant management has considered options to reduce the use of water and energy, alongside the related payments for supply of water, energy and WWT. Options include the following:

anaerobically pre-treating waste water to generate biogas at the plant site reducing water use for pump-sealing water;

removing organic material and microbial growth potential in water from CIP;

reusing condensate from the water evaporation during powder production.

### 5.3. Eco-efficiency comparison: WW pre-treatment option

For the above option of in-house WW pre-treatment, anaerobic digestion transforms organic waste products (mainly fats, proteins and sugars) into energy by producing biogas, which can substitute for natural gas usage or generate heat and power. The pre-treatment also reduces the organic-waste load on the WWTP and thus its energy usage. Potential changes in eco-efficiency have been evaluated with the following indicators.

#### 5.3.1. Economic analysis

For the TVA, indicators are freshwater abstracted and process energy (electricity costs), chemical-input costs, WWT costs (internal or external) and O&M costs. The savings in external payments for WWT would be significantly countered by the extra investment cost, so the TVA shows a small increase over the baseline scenario (Andersen, 2013). As regards the redistribution, the dairy gains most of the increase, while the biogas plant incurs a large loss, as shown in Table 2 (based on EcoWater, 2014b).

#### 5.3.2. Environmental analysis

Midpoint impact indicators are: freshwater abstracted, process energy (GHG emissions), chemicals used (esp. salt and HNO3), pollutant-emissions.

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:

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

- Reduced load on WWTP → reduced power consumption and $CO_2$ emissions
- Reduced biogas production → reduced downstream power and heat production (Andersen, 2013).

Regarding the latter point, in-house anaerobic pre-treatment would reduce the biogas supply to district heating, which then would need more fossil fuels. This decrease is compensated by the total energy savings in the dairy and WWTP (EcoWater, 2014b).

The result would be a modest reduction in fossil-fuel usage and GHG emissions (by 11%) relative to the baseline scenario. The Fig. 6 spider diagram compares the in-house WWT option (diamond-shaped nodes) with the baseline situation (circle-shaped nodes). The former offers modest benefits from a whole-system value-chain perspective; by contrast, benefits would appear greater in a micro-level focus on the dairy per se. So a whole-system assessment adds information about how an option would affect the larger system.

### 5.4. Arla workshops

In October 2013 the EcoWater project held a workshop at the case-study Arla plant. This started with presentations on the company's resource-efficiency objective. For its 'Closer to Nature' motto, 'We want to appear as a sustainable and responsible company in balance with our surroundings.' This effort runs from the farmer supply chain to the processing plants. For example, Arla's innovation seeks a 'natural' milk-protein ingredient through a new caseine process avoiding use of acid hydroxides (Hansesgaard, 2013).

Such innovations have been driven by the company's need for cost-efficient production processes and its consumer reputation. The company also anticipates higher environmental taxes, scarcer water and higher costs in the future. Such drivers have converged in the company's Environmental Strategy 2020 and specific investments (Nørgaard, 2013).

After those presentations, the EcoWater team presented its whole-system value-chain assessment of in-house WW pre-treatment, which would offer modest benefits (Andersen, 2013, Fig. 6 above). Arla representatives agreed with that assessment. They saw the EcoWater eco-efficiency assessment method as more generally helpful for considering whole-system effects. They expressed interest in several follow-up steps, e.g. 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. The workshop also discussed how the benefits of Arla's technological improvements may be scale-dependent, e.g. depending on whether they multiply small-scale changes in many places or else enlarge a centralised operation, requiring longer-distance transport.

In June 2014 a follow-up workshop discussed the application of the eco-efficiency concept to more Danish dairies, both within and outside the Arla group, with the aim to generate a benchmark which can guide the sector towards higher eco-efficiency. As a first step towards benchmarking eco-efficiency, workshop participants agreed to include five cheese-producing dairies through new

**Table 2**
Redistribution of economic value and environmental burdens in the WW pre-treatment option.

|  | Dairy: water use and WWT pre-treatment | WWT operator | Biogas plant | Eco-efficiency of total value chain |
|---|---|---|---|---|
| Econ. Δ | Econ. + | Econ. + | Econ. − | Increase |
| Env. Δ | Env. + | Env. + | Env. − | |

research activities on water-efficient dairies. The value-chain assessment would enable the dairies (i) to start a discussion on eco-efficient solutions with the water and wastewater utilities and (ii) to assess whether eco-innovative technologies identified in milk powder-producing dairies can be applied also in cheese-producing dairies.

## 6. Discussion and conclusion

Eco-innovation combines economic advantage with lower resource burdens by various means, including process upgrading in water-service processes. This study investigated the potential for such process improvements in two large manufacturing companies, Volvo and Arla. Relative to their respective industrial sector, these companies represent strong prospects for improvements in water-service processes, especially regarding chemical inputs and wastewater. Impetus comes from the companies' environmental policies, as well as from external drivers such as future higher costs and resource scarcity, beyond legislative requirements. These various drivers link the companies' efforts towards greater resource efficiency and lower resource burdens; such improvements result from more than economic motives alone (cf. Clayton et al., 1999; Markusson, 2011).

In particular: The automotive industry has generally directed eco-innovation at fuel efficiency or alternative fuels, or on pollution control outside manufacturing plants; Volvo has also been adopting or considering changes which lower resource burdens in the manufacturing process. The dairy industry has generally directed eco-innovation at $CO_2$ reductions from renewable energy sources, or on more efficient transport; Arla Foods also has been adopting or considering changes which lower resource burdens in water-service processes.

Such eco-innovations involve more complex interactions beyond the production site, so the options warrant a whole-system comparative assessment. The well-known eco-efficiency concept helps to evaluate potential improvements by comparison with the baseline situation. But such evaluation has generally focused on specific production sites, while neglecting wider effects; this micro-level focus reinforces sub-optimal solutions and neglects better opportunities. To address the methodological gap, the EcoWater project has analysed the entire water-service value chain through meso-level interactions among heterogeneous actors such as process-water users, providers and WWT companies.

The project has developed a methodology to obtain the necessary information, to involve stakeholders in the assessment and to facilitate their joint discussion on alternative options. To assess meso-level eco-efficiency, each study combined information from relevant stakeholders and LCA databases, as a knowledge-basis for comparing specific alternative options with the baseline situation. As methodological limitations, some data depend on assumptions and extrapolations from past experience. The method also involves judgements about where to set the meso-level boundary; this depends partly on the resource burdens being prioritised, the improvement options being assessed and their interactions with a wider value chain.

Each study stimulated internal company discussions on the need and means to evaluate whole-system effects of investment decisions. Prior discussions with stakeholders attracted their attendance at workshops to discuss improvement options and the meso-level eco-efficiency assessment for comparing them. Inter-organisational cooperation helped to anticipate how meso-level resource-efficiency relates to lower burdens in WWT, e.g. by reducing energy demands and climate impacts.

Multi-stakeholder discussion identified potential benefits or limitations which have wider relevance. As in the Volvo case, more

advance information would help the WWT company to realise the full benefits of process improvements in the main company. As in the Arla case, a company-level improvement can be deceptive as regards resource efficiency. Stakeholders expressed interest in jointly discussing investment strategies, as well as extending the whole-system method to more options and contexts.

The EcoWater assessment method can be extended to any water-service system which has adequate data for the main aim – to compare economic and environmental indicators of different options. By involving stakeholders in such comparisons, the method can facilitate better decisions improving meso-level resource efficiency. Progress will depend on stakeholders sharing knowledge and responsibility, thus overcoming fragmentation within and across companies.

As wider implications, the two improvement options here complicate 'eco-innovation' as double-eco benefits: win–win for whom, where and what level? (cf. OECD, 2012). In the Volvo silane-based option, the TVA increases but would be redistributed in favour of the investor company, at the expense of other value-chain actors (see again Table 1). In the Arla WW pre-treatment option substituting biogas for fossil-fuel inputs, likewise the TVA increases but is gained mainly by the investor company, at the great expense of the biogas company. Resource efficiency increases at the dairy's micro level but little at the meso level, mainly because resource benefits are shifted from the biogas company to the investor company; WW pre-treatment also somewhat reduces energy use by the WWT operator.

Thus potential benefits have tensions between different stages, actors, micro vs meso levels, etc. These tensions have been revealed through a meso-level eco-efficiency assessment, informing multi-stakeholder discussion of each others' perspectives (cf. Grin et al., 2010: 273). Such discussions can help stakeholders to develop mutual interests and shared responsibility towards better options.

## Acknowledgements

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