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EcoWater report

Cross-comparison of Case-study Outcomes

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EcoWater ran 2011-2014. The project is presented in more detail on http://environ.chemeng.ntua.gr/ecoWater/
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Meso-level eco-efficiency indicators to assess technologies and their uptake in water use sectors

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Executive summary

The EcoWater project developed a method for using eco-efficiency indicators to compare various improvement options with the baseline situation at the meso level, i.e. in a systemic approach. The meso-level focus analysed interactions among heterogeneous actors in water-use systems, both in the current situation and for the implementation of potential eco-innovations. The method was applied to eight case studies spanning three water use sectors (agricultural, urban and industrial). Each case made methodological judgements about numerous aspects of eco-efficiency assessments. Through such assessments, each case study facilitated multi-stakeholder discussions on improvement options, on factors influencing their adoption and on policy implications.

This report compares those methods, judgements and their results across the case studies. As these comparisons reveal, improvement options are case-specific, e.g. dependent on the context, the environmentally weakest stage, the potential for system improvement and data availability. The general method was adapted to each case, especially so that the meso-level boundary and indicators encompass potential effects of the eco-innovations being evaluated. In this sense the step-wise method is iterative, sometimes reconsidering previous steps. The meso-level analysis adds information about effects beyond a micro-level focus on an organisation's internal processes, sometimes reducing or complicating the apparent benefits at that level.

In each case study, few options would be 'win-win' by improving all environmental indicators, increasing total value added (TVA) and financially benefiting all value-chain actors. Selecting the most eco-efficient options entails tensions and trade-offs among various objectives, thus complicating eco-innovation as a win-win strategy. The potential to optimise meso-level eco-efficiency, alongside various trade-offs, highlights the value of sharing stakeholders' different understandings through meso-level discussion, in ways appropriate to each specific context.

As shown by comparisons among diverse cases, the general method was robustly applied – to assess options for eco-efficiency improvements, to evaluate their relative meso-level benefits, and to facilitate multi-stakeholder discussion on optimising the system. So the method has wider relevance to any meso-level water-service system.

The report is structured as follows: Introduction to the methodology (section 1), results of the cross-case comparison with overall conclusions (section 2), in turn referring to results of each case study (sections 3-10), and documentary references.

Contents

1 Introduction to the cross-case comparisons

This report compares how the various case studies adapted and elaborated the EcoWater project's general method through various judgements. Cross-case comparisons help clarify the method's wider relevance to compare options for eco-efficiency improvements, as well as to facilitate their adoption. The report fulfils T5.2, Cross-comparison of Case Study outcomes:

> *The Task will involve the presentation of consolidated results from the Case Studies in a coherent format to allow for a cross-sectoral assessment of eco-efficiency indicators use, particularly focusing on how these can be used to facilitate decisions on the uptake of innovative technologies, i.e. how results can affect the policy, social, economic and management factors used by the decision makers. The output from the task shall be readily useable for future refinement of meso-level eco-efficiency indicators (EcoWater DoW).*

For information sources, this report draws on numerous documents of the EcoWater project, especially deliverables, internal reports and workshop reports. Posters are available on the general methodology and each case study [http://environ.chemeng.ntua.gr/EcoWater]. The cross-case comparisons also draw on wider literature such as other projects' reports and journal papers.

Each case study tells a story at two levels:

- Meso-level socio-technical dynamics, i.e. interactions among heterogeneous actors around recent and potential eco-innovations; and
- Methodological judgements in investigating specific examples and options, as a window of opportunity into those dynamics.

For each case study the methodology was structured in four main steps: the meso-level value chain, baseline eco-efficiency assessment, options for eco-innovation improvements and eco-efficiency comparisons of them (as in the sequence of the Case Study Development Process). Each step was influenced by the previous one, but also vice versa by reconsidering previous judgements. For example, improvement options sometimes expanded the meso-level system boundaries and/or eco-efficiency indicators. Thus the method was iterative in practice.

For simplicity of presentation, case-study characteristics below are structured around four sub-sections, while also including examples of the iterative relations among steps.

1. **The meso-level system**, which explains the main concepts, as a basis to compare the following: the sectoral contexts for eco-innovation, the specific focus for upgrading each water system, and judgements on the meso-level system boundaries.
2. **Eco-efficiency assessments,** comparing results of the following: the most relevant indicators for the baseline eco-efficiency, distinctions between the foreground and background of the system, selection of technologies which may upgrade the meso-level system, trade-offs among various aims, and

redistribution of total value added among actors in the water-service value chain.

3. **Prospects for adopting eco-innovations**, which compares results of the following: organizational responsibilities for meso-level improvements through eco-innovation, multi-stakeholder discussions illuminating meso-level interactions and improvement options, and policy implications for facilitating such improvements.
4. Conclusions on the methodology for its robust application and wider relevance.

After Section 2 on cross-case comparisons, a similar structure is followed for each case study, giving examples which are methodologically most important or difficult. From all those patterns and variations, the method becomes more robust and generally relevant.

2 Results of cross-case comparisons

2.1 Meso-level system methods and results

2.1.1 System upgrading: Concepts

Each EcoWater case study illustrates a water-service system, i.e. a system which provides water suitable (in terms of quantity and quality) to meet the requirements of specific activities, or, in other terms, 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, 2012).

The innovative options are focusing on the water-service system; each case initially listed several innovative practices which could upgrade the system towards greater eco-efficiency. Although called 'technology options', these depend on wider innovative practices which may need improvement and/or could be newly adopted, as a basis to fulfil the potential benefits of technology adoption. Each case eventually selected a few options to investigate in detail by comparing their potential eco-efficiency gains.

Eco-innovation 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 above), or else the production chain (e.g. less inputs, lower-emission inputs or reuse of emissions, as in the vertical axis). In the diagram, 'technologies' is short-hand for innovative practices which depend on more than technologies.
- Process or product: Within the production chain, process upgrading uses inputs 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, e.g. through in-house WWT, reuse, recycling, etc. (WssTP, 2013).

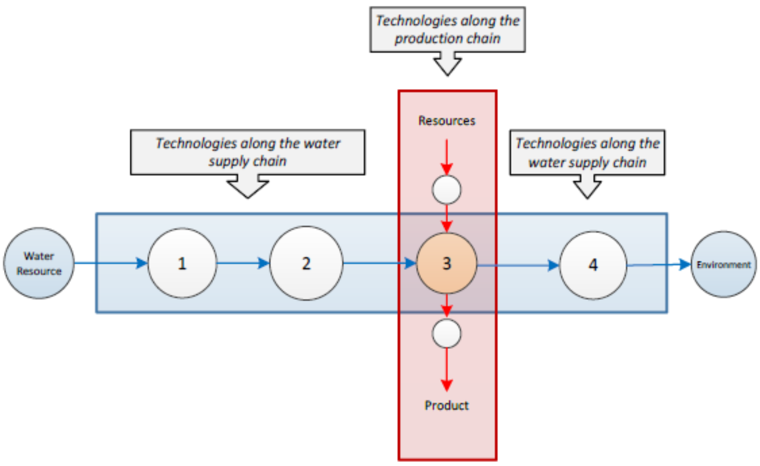

Figure 1 Potential improvement sites along the meso-level value chain (EcoWater, 2013: 5)

Innovative options were evaluated in relation to the entire water-service value chain at the meso level, also known as a systemic approach. Some organisations' representatives see the need for such a perspective, rather than consider options one-by-one. This motivates their interest in the EcoWater method, which illuminates broader options.

2.1.2 Eco-innovation context of each case study

For each case study, the context matters in several ways. It affects the following aspects: the representative character of the case, the scope for lowering environmental burdens relative to the baseline situation, stakeholder interactions and other influences on investment decisions, the organisational capacity and motives for system upgrading, and the relevance of policy frameworks.

The eight case studies provide diverse contexts for clarifying and refining the EcoWater method, especially for comparing the eco-efficiency of several improvement options within a system.

Starting from a sector or water system in a geographical area, each case study sought a more specific focus for feasibly developing the EcoWater methodology when the project began. Not by coincidence, when approached by the case-study team, organisations most willing and able to cooperate with the project had already made significant investment in innovative resource-efficient practices and were considering extra improvements. Impetus came from their environmental policies and/or from external drivers such as future higher costs and resource scarcity, often going beyond current legislative requirements. So each case represents the sectoral potential in a symbolic sense, rather as an average or typical example which would have weaker prospects for improvement.

Context: Comparative results

Agricultural Water Use Systems

In both case-study areas, SCADA technology at hydrants allow each farm to abstract water on demand at any time and charges them according to a volumetric water pricing; but the use was not optimised for crops' water needs.

CS1 Sinistra Ofanto is an older irrigation system with which had implemented at least partly several eco-innovations for water-use efficiency. Nevertheless the area has water-pollution problems and a recurrent water scarcity, leading some farmers to abstract groundwater during dry summer periods.

CS2 Monte Novo is a new irrigation system which draws water from an expensive reservoir project which created water abundance, resulting in a high water price and a search for more water-efficient techniques.

Urban Water Supply Systems

The water operator has a minimal use of fossil fuels for different reasons in the two cases, alongside a policy to enhance environmental sustainability. But water users depend on fossil fuels for water heating.

CS3 Sofia: The system obtains water from a gravity-fed source.

CS4 Zurich: Hydropower has supplied the water system for several decades, partly in response to the 1970s oil crisis. The water operator has optimised the efficiency of its own processes.

Industrial Water Use Systems

Case-study companies have several examples of eco-innovation through in-sourcing, as well as reducing and/or re-using wastes:

CS5 Biella Textile Industry: Some companies have substituted herbal dyes for synthetic-chemical ones; several companies have established in-house facilities for the WWT process.

CS6 Cogeneration: The energy company had already invested in various eco-innovations for resource efficiency, especially heat-only boilers linked with district heating where new residential buildings are being constructed.

CS7 Arla Dairy Industry: Its dairies' WWT sludge is generally converted to biogas. IT systems control the conditions and flows of every process stage.

CS8 Volvo Automotive Industry: Many plants have established water-recycling and/or closed-water systems, thus going beyond the industry's general focus on energy-efficient vehicles at the user stage.

2.1.3 Meso-level boundaries

Meso-level interactions

In the EcoWater project the meso level is defined both as a physical system and as interactions among heterogeneous actors (based on Schenk, 2007), by:

- Coupling of individual technologies and groups of actors both in the water supply and water use stage, resulting in interdependencies and interaction.
- Focus on dynamic behaviour of interdependencies of individual system elements (EcoWater D1.1).

Such interactions arise from various actors which are directly or indirectly 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, and the analysis of their (economic) interrelations is a research objective in EcoWater, as these can influence technology uptake.
- Indirectly involved actors, referring to governmental institutions/authorities, consumers and further stakeholders who might benefit from or indirectly influence technology implementation and uptake (D1.8: 14).

In each case study the meso level lies at the intersection of two chains and their actors (Figure 2):

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

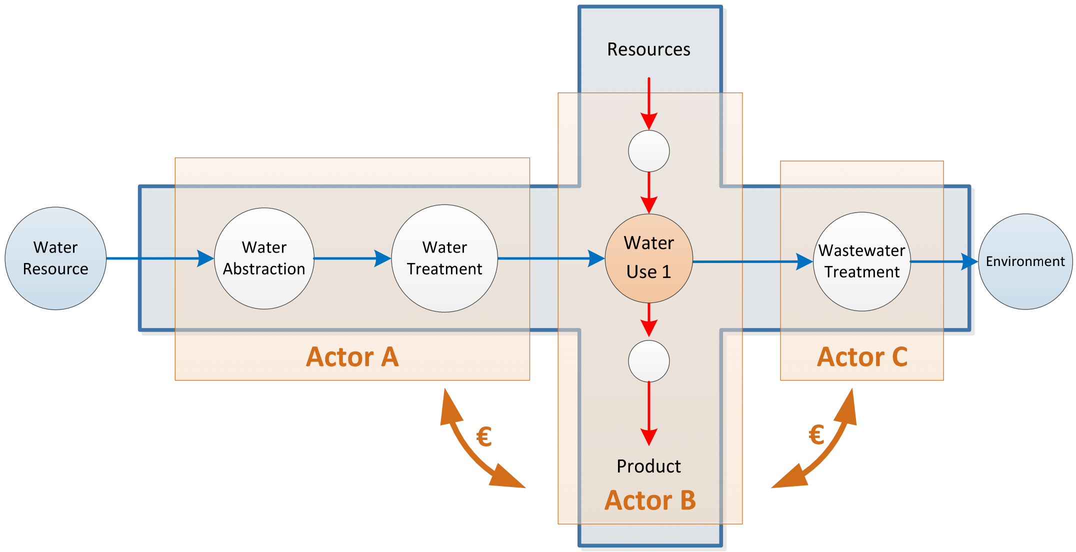

Figure 2 Meso-level water-use system (EcoWater, 2013: 7)

Meso-level boundaries: comparative results

A methodological issue has been where to set the meso-level boundary. Not initially obvious in the case studies, the boundary was sometimes clarified or expanded later in the study. The boundary judgement depends partly on the resource burdens being prioritised, the improvement options being assessed, data availability for them, and their interactions with a wider value chain. Such boundary judgements relate to how eco-innovation potentially improves a system. Each case study started from a large-scale meso level, eventually choosing a small-scale focus as a window into potential improvements, e.g. a specific process or site within a larger system. Meso-level boundary judgements are illustrated as follows:

Agricultural Water Use Systems

These two cases started from a standard set of actors: water supplier, water users organisation (WUO) and farm-level water use; farmers pay no fee for effluent, at least not in the two cases. The system boundaries remained constant through the studies. Product price depends indirectly on consumers, especially for a potential change to organic (bio) products; but consumers lie beyond the meso-level system. In CS1 Sinistra Ofanto the water-users' organisation proposed to reuse WW from other sectors, which would expand the meso-level system, but the potential change in eco-efficiency was not assessed.

Urban Water Supply Systems

Unlike the other sectors, here water supply per se is the product as well as the service. Both urban case studies defined the meso-level system as the water supply, use and treatment stages; the system boundaries remained constant through each study. But judgements were necessary about including water users without centralized sewerage system, and about distinguishing among types of domestic water users (CS3).

The studies investigated options for upgrading all three main stages. For at least one option, the economic and environmental aspects were split inside/outside the system: For phosphorous recovery, the financial cost would be paid by the water operator and so lie within the meso-level system, but the environmental burdens and potential reuse benefits lie outside the boundary (CS4 Zurich); a future study could expand the boundary to encompass those environmental aspects.

Industry Water Use Systems

CS5 Biella started from the entire area's textile industry and then focused on the dyeing process, which encompasses numerous SMEs. Only a few expressed interest to participate in the study; not coincidentally, these SMEs had already made technological improvements and were considering extra ones. Eventually the study focused on two companies as representing two generic types in the wider industry. One company using herbal dyes depends on long-distance quality markets to obtain a higher price, but the study did not consider options for changing or expanding such markets, so the methodology did not need to widen the meso-level system.

CS6 cogeneration focused on how the energy company could reduce, reuse or sell surplus heat and ways of better matching heat with demand, thus reducing demands on natural gas (D4.1). Eventually the study focused on one plant willing to cooperate with the project, after the original plant turned out to be reluctant. The system boundaries were extended to actors potentially using the surplus heat as well as to the natural gas supplier.

CS7 started discussion with two of Arla's Danish dairies and then focused on improvement options at one plant. Initially the meso level focused on interactions between the water supplier, dairy and WWTP. Arla dairies depend on a large transport of milk and other milk ingredients by lorry; they seek options for reducing such transport and their resource burdens, so a broader system boundary helped to evaluate such options (D4.2: 29).

CS8 Volvo focused on truck-production units considering a substitute or extra technology which would lower resource burdens. Each vehicle's cabin is transferred across two sites in a production process, so a broader system boundary helped to compare improvement options at both sites and to identify any interactive changes in resource burdens. The meso level encompassed interactions between the water supplier, vehicle plant and WWTP at both sites (D4.2: 39).

2.2 Eco-efficiency assessment

2.2.1 Baseline assessment

Methodological issues

From the baseline eco-efficiency assessment of the meso-level system, each case study identified the environmentally weakest stages, i.e. with the greatest resource burdens. These stages became the focus for improvement options through innovative practices.

An eco-efficiency ratio has two main components, each with its own indicators, as elaborated in the project's guidance document (EcoWater, 2013):

- Economic: Total Value Added (TVA) to the product by water processes, i.e. the water-service value chain. 'Total' denotes the economic value minus various costs of water abstraction, treatment, WWT, etc.

- Environmental: Initially the studies used somewhat different indicators. Eventually the project agreed on a standard list of midpoint impact categories (see Figure 3). 'The midpoint indicator is chosen in a way that all LCI are appropriately aggregated as early as possible in the cause-effect chain' (JRC, 2010: 8).

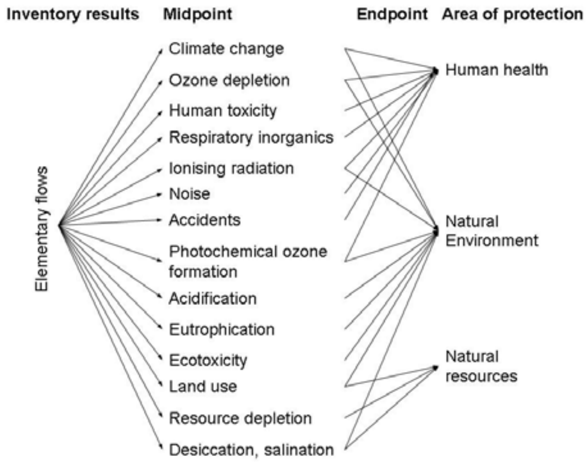

Figure 3 Framework of impact categories for characterisation modelling at midpoint and endpoint levels (JRC, 2010: 3)

In all eight case studies the system's environmental performance was assessed through environmental midpoint indicators, representative for the specific system in its case study context. Environmental impacts of the foreground system were calculated from the characterisation factors in the CML-IA database, while the factors for the background system are obtained from the EcoInvent database, using the CML 2001 Method (JRC, 2011). Economic data came mainly from the organisations under study (EcoWater D1.1).

A potential difficulty was how to obtain adequate, relevant data. Its availability has 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 partly on assumptions and extrapolations.

Each environmental indicator may derive from several 'elementary flows' (Figure 3) or parameters, i.e. specific measurable substances; so the assessment needed judgements on identifying and combining those parameters. As another issue, the indicator value per se may reveal little about environmental-resource burdens, which are contingent on specific substances in their wider contexts, e.g. whether water supplies are abundant or scarce. 'Impact factors' link indicators with baseline resource contexts.

To identify the origin of resource burdens within each meso-level value chain, the baseline assessment distinguished between foreground and background systems:

- The boundaries of the foreground system include all the processes whose selection or mode of operation is affected directly by decisions based on the study. These processes are directly related to the water supply and the water use chains.

- The background system includes all other activities and is that which delivers energy and materials to the foreground system, usually via a homogeneous market so that individual plants and operations cannot normally be identified.

This distinction helps to clarify how and where eco-innovation improvements in the system could best reduce resource burdens.

Alongside all those common methodological issues, some different ones arose in the three sectors of the case studies.

- Agriculture: As an environmentally open system, agriculture has numerous annual variations, e.g. rainfall, farm-level yield, water availability, product prices, etc. Also spatial variations: cultivation methods and water pressure vary across crops, even for the same crop within the case-study area. So the baseline assessment had to make judgements about averaging some variations and/or assessing them separately (e.g. dry versus normal years, high versus low-water pressure), as a baseline for assessing improvement options.
- Urban: Unlike the other two sectors, here water itself is the product. For the TVA assessment, economic value added by the water had a less obvious method than in other sectors, so 'willingness to pay' served as a basis for the calculation.
- Industry: The CS5 Biella study identified different types of textile-dyeing plants which warrant a separate baseline assessment, in order to anticipate the different effects of the same improvement option.

Each component of eco-efficiency was calculated with a dedicated tool: Economic Value chain Analysis Tool (EVAT) and Systemic Environmental Analysis Tool (SEAT). The data and calculation methods were discussed with stakeholders providing the information. After refinement through the project's case studies, these tools were made publicly available at: http://environ.chemeng.ntua.gr/ewtoolbox/

Relevant indicators and baseline eco-efficiencies: comparative results

According to the case study reports (D2.3, 3.3 and 4.3), indicators were selected on four considerations within the system boundary: pollution context, resource depletion, environmental regulations, and the water-user's strategies. Which indicators were most relevant? As can be seen from Table 1 (left column), no case study selected all 12 indicators as relevant for their particular case study. All case studies had six common indicators: freshwater depletion, climate change, acidification, human toxicity, aquatic toxicity and terrestrial ecotoxicity.

The eco-efficiency is the ratio between the total value added (TVA) by the water use and the environmental impact of the water use system. The eco-efficiency values therefore depend on numerous factors: a) the system boundary and number of actors in the system either providing water service or using water service and the context in which the system is operated, b) the total value of the water use, which depends on the product or service provided in the system and the cost of its provision, which in turn depends on the pricing of water and energy, etc. and c) the environmental impacts, which depend on various inputs, e.g. water, energy and chemicals.

Table 1. Indicators and eco-efficiency in baseline scenarios

Indicators	Agricultural		Urban		Industrial			
	CS#1	CS#2	CS#3	CS#4	CS#5	CS#6	CS#7	CS#8
Climate Change (€/t$CO_{2,eq}$)	1081	186	94	373	1351	57.5	30.1	44000
Stratospheric Ozone Depletion (€/kgCFC-11_{eq})	NR*	NR	>10^6	>10^6	NR	NR	NR	>10^6
Eutrophication (€/kg$PO^{-3}_{4,eq}$)	109	15.4	41.7	4.9	1025	NR	0.99	42000
Acidification (€/kg$SO_{2,eq}$)	82.6	21.8	4.4	215	366	78.4	3.1	15000
Human Toxicity (€/kg1,4DCB_{eq})	19.9	1.7	1.1	4.5	6.8	28.9	28.5	2000
Aquatic Ecotoxicity (€/kg1,4DCB_{eq})	74.5	10.9	13.3	15.6	0.8	8391	737	1800
Terrestrial Ecotoxicity (€/kg1,4DCB_{eq})	3866	106	513	6000	9.5	2169	630	>10^6
Photochemical Ozone Formation (€/kg$C_2H_{4,eq}$)	8417	518	111	8822	6959	602	3271	>10^6
Respiratory Inorganics (€/kg$PM_{10,eq}$)	3007	143	22.5	1257	NR	15498	NR	NR
Minerals Depletion (€/kgFe_{eq})	7948	923	42.4	NR	NR	NR	NR	NR
Fossil Fuels Depletion (€/MJ)	4.9	0.007	0.01	0.03	NR	0.002	NR	NR
Freshwater Depletion (€/m^3)	7.0	0.6	1.1	31.6	122	6.1	203	17000

The results of the baseline eco-efficiency assessment are presented in Table 1. The cross-comparison of these case studies leads to the identification of potential areas of improvement for by highlighting the weak stages in the water supply chain of each case study and comparing similar stages/processes across case studies.

For example, when comparing the two agricultural case studies, it is obvious that the the Sinistra Ofanto irrigation scheme has a better eco-efficiency performance than the Monte Novo irrigation scheme, mainly explained by the increased fuel consumption for pumping in the latter case.

Similar conclusions may be drawn by comparing the two urban case studies. It is obvious that the Sofia urban water supply system has worse eco-efficiency performance. This is due to two main reasons: (a) the energy mix for electricity production in Bulgaria is less environmental friendly than the one in Switzerland and (b) the infrastructure in Bulgaria is older, leading to a very high amount of water leakages, and a very lower eco-efficiency value for the freshwater depletion indicator. TVA for Zurich is four times higher than for Sofia, reflecting their wider difference in GDP per capita. Decades ago Zurich invested in hydropower to replace fossil fuels, so the background resource burdens from energy use are relatively lower.

A similar comparison is not meaningful for the industrial case studies since the production lines differ a lot and the main conclusions are case (or sector) specific. However, it is still obvious that the main environmental weakness of Biella is aquatic ecotoxicity (and the other toxicity related issues), since the relevant indicator is at least 10 times lower than any other indicator. Similar to that, the most important environmental issue of the dairy industry is eutrophication, due to high amounts of BOD, COD and organic residues released to the environment. As expected, the energy industry has the worst performance among all case studies concerning the climate change indicator. The values of the eco-efficiency indicators for the automotive industry are of a different order of magnitude to the high value of the final product (compared to all the other 7 products) which highly affects the TVA of the system.

Therefore the high versus low values should be interpreted by analysing the TVA and environmental impact in each case-study context.

Furthermore, the case study cross comparison may also lead to non-case specific results, such as:

- Definition of a range for each indicator and reference values for normalizing them;
- Technology benchmarking by providing a reference value for eco-efficiency improvements;
- Information for prioritizing and targeting policy actions (e.g. supporting competitive sectors like industrial or agricultural with economic incentives)

2.2.2 Technology options comparison

In this project, technology is a short-hand term for eco-innovation, i.e. innovative practices which improve eco-efficiency. Although these improvements may change or add a technology, they can take other forms, e.g. by using organic fertiliser or herbal dyes instead of chemical ones, or linking waste heat with residential buildings.

'Closing the loop' has been a general perspective for turning waste or surplus outputs into useful inputs, e.g. by changing input-output sequences or WWT processes for such reuse (Hiessl et al., 2001; ChemWater, 2012, WssTP, 2013). Closed-loop processes can extend economic value spatially and qualitatively – through extra actors, resource uses and products – or else can internalise processes within a unit, thus taking away control from another actor. 'Closing the loop' has been generally more straightforward when using emissions for energy production or construction materials. By contrast, recycling materials or water as inputs raises difficulties with quality standards, reliability and trust issues – even within a production unit, and especially for such flows among different actors.

In each case study, the eco-efficiency assessment was initially carried out for one or two technology scenarios, i.e. innovative practices. These assessments were meant to clarify the method (including the meso-level boundary), to make comparisons with the baseline situation and to present preliminary results at the first multi-stakeholder workshop. The assessments were extended to more options and then to combinations. Each case-study section below explains a few options and/or combinations.

Technologies to upgrade the system: comparative results

Table 2 shows several technologies which were assessed in the case studies. As they show, eco-efficiency could be increased by introducing technologies in the water supply, waste water treatment and/or the water use (production) stage. Beyond the assessment of eco-innovations, they were correlated with three different policy scenarios: resource efficiency, pollution prevention and circular economy.

Table 2 Technologies in the water supply and waste treatment chain

Technologies	Stage	Resource Efficiency	Pollution Prevention	Circular Economy
Variable speed pumps	Water Abstraction and Distribution	✓	✓	
Pressure reduction turbines		✓	✓	✓
Smart pumping		✓	✓	
Solar pumping		✓	✓	
Membrane distillation	Water Treatment			
Micropollutant removal	Wastewater Treatment		✓	
Advanced phosphorus recovery			✓	✓
Solar drying of sludge			✓	✓
Anaerobic pre-treatment of wastewater			✓	
Advanced oxidation processes			✓	
Membrane bioreactor			✓	

As can be seen in Table 2, technologies in the water abstraction and water treatment stages have a broad relevance to all three policy scenarios, regardless of the specific conditions in the case studies. This is unsurprising because water-supply systems and technologies are widely applied across all three sectors (agriculture, urban and industry) to provide the water for various uses. The water-treatment stage is much more dependent on the specific use of the water; likewise the post-use wastewater treatment is more dependent on the specific pollution characteristics resulting from the water use. Those two stages had no common options for the urban cases because their contexts greatly differ in legislative framework and engineering system (D2.4).

From Table 3 it is also clear that relevant technologies in the water-use stage are case-dependent in all three scenarios. As another contextual aspect, the scope to improve a system depends on whether it is already optimised in some respects, as well as whether the sub-optimal aspects relate to the foreground, which is more readily improved (than the background) by changes within the system. So an innovative practice or technology must always be evaluated in a specific context.

Table 3 Technologies in the water-use stage

Sector	Resource Efficiency	Pollution Prevention	Circular Economy
Agricultural Water Use	Regulated deficit irrigation Drip & sub-surface drip irrigation	Use of sludge Use of organic fertilizers	
Urban Water Supply	Water saving appliances	Solar water heating Drain water heat recovery	Water reuse technologies
Textile Industry	Jet dyeing machines Automatic dye and chemical despensing systems	Use of natural dyes	
Energy Production Industry	Heat only boilers Thermal energy buffer		Expansion of the heat distribution network Preheating potable water
Dairy Industry	Product and water recovery from CIP Cleaning and reuse of condensate	Advanced oxidation and UV	Cleaning and reuse of condensate
Automotive Industry	Silane-based metal surface treatment Recycling of process water and chemicals		Recycling of process water and chemicals

Win-win or trade-offs from eco-innovation? Comparative results

Resource-efficient innovation uses inputs in more efficient ways, thus also potentially saving process costs. By combining such benefits, eco-innovation has been widely seen as 'enabling win-win synergies' (OECD, 2012). Yet eco-innovation generally entails tensions among objectives: 'Like any innovator, an eco-innovator must deal with trade-offs. The trade-offs depend on the state of technology and contextual factors such as prices and infrastructure' (Kemp and Oltra, 2011: 250).

In the EcoWater case studies, few options would improve the most important environmental indicators (for the greatest resource burdens), increase total value added (TVA) and financially benefit all actors in the meso-level value chain. Most options reveal tensions and trade-offs among various objectives, e.g. economic versus environmental aims, different resource burdens, process stages, micro vs meso levels, economic beneficiaries versus losers, short versus long-term return on investmen, economic predictability, etc. (Levidow et al., 2015, forthcoming).

Table 4 illustrates a few eco-innovations as win-win but others as trade-offs between environmental benefits or economic beneficiaries. The Table shows changes in environmental indicators, TVA and its distribution via NEO. It does not show how the TVA/environment ratio changes eco-efficiency for specific indicators; for more detail, see the specific case studies.

Table 4 Eco-innovation win-win or trade-offs?

Eco-innovation *Win-win* only where stated	Δ environmental indicators None worsen unless stated	Δ TVA & distribution No losses unless stated below.
CS1 SDI: *win-win* (generally)	Several are improved (from greater water-use efficiency).	TVA rises. Some farms have higher NEO, but not olive fields.
CS1 super-intensive scenario: *win-win*	All are improved (from reducing water and energy demands).	TVA rises. Most farms have higher NEO.
CS2 organic fertilisers in olives	Several are improved (by replacing for synthetic chemicals).	TVA falls from lower production; farmers have lower NEO.
CS2 super-intensive scenario: *win-win*	Several are improved (from resource-efficient inputs)	TVA rises. All actors have higher NEO.
CS3 domestic appliances	Several are improved (by saving water and energy).	TVA rises. Households have higher NEO, but water operator loses NEO.
CS3 solar heating: *win-win*	Several are improved (esp. by replacing fossil fuels).	TVA rises. Households have higher NEO.
CS4 micropollutants removal	Human ecotoxicity improves, but other indicators worsen from energy inputs.	TVA declines. Water operator has lower NEO, unless water price rises.
CS4 smart pumping: *win-win*	Several improve (esp. from lower energy use).	TVA rises, water operator gains NEO.
CS5 resource-efficiency: *win-win*	Several are improved.	TVA rises. All actors gain NEO.
CS5 pollution-reduction	Several are improved.	TVA rises. Industrial Unit A would lose NEO; Unit B would gain NEO.
CS7 WW pre-treatment	Several are improved, despite shifting biogas from outside to inside dairy.	TVA rises. Dairy gains NEO, but WWTP and biogas plant lose NEO.
CS8 silane-based process	Several are improved.	TVA rises. Plant gains NEO, but WWTP loses NEO.

By definition, 'win-win' options improve or maintain all environmental indicators and likewise all actors' NEO. Amongst the few in Table 4, some reduce demands for fossil-fuel and/or water inputs, e.g. CS1 subsurface drip irrigation (SDI), better than surface-drip irrigation; CS3 solar heating replacing fossil fuels; CS4 smart pumping reducing energy demand. Some options substitute more resource-efficient inputs, e.g. combinations in CS2 and CS5.

For options which would most increase eco-efficiency, the increase was generally due to lower resource burdens, more (or rather) than greater TVA. Investment costs can limit the financial benefit and reduce eco-efficiency for indicators which have environmental improvements. As an exception, the silane-based technique substitutes different inputs, requiring no new equipment, thus increasing TVA (CS8 Volvo). In cases requiring new equipment, the extra cost could eventually be recouped through lower operational costs, but there are uncertainties about predicting or influencing the long-term economic variables (e.g. CS1&2 agricultural systems, CS5 Biella).

For combinations of options, benefits can be more than additive through synergies across process stages. Relevant synergies have been presumed and incorporated in the assessments, though without explaining such complexities in the project reports. Generally the greatest eco-efficiency comes from combinations enhancing resource efficiency, while sometimes also reducing pollution (CS5). In the agricultural case studies, the greatest eco-efficiency gains would come from 'super-intensive' scenarios combining three options to reduce water and energy demands (CS1) or in order to substitute more resource-efficient inputs (CS2).

Pollution-reducing options may require great investment, either lowering or increasing the TVA, while even increasing other environmental burdens. In particular, micropollutants removal regularly consumes materials dependent on fossil-fuel inputs, whose environmental burdens pose a trade-off with lower human ecotoxicity (CS4). Some pollution-reducing input-substitutes such as organic fertilisers or natural dyes are more expensive than their synthetic counterparts but can increase the product value and thus TVA in some cases (CS1, CS2 and CS5).

Distributional Issues: Comparative results

As a pervasive tension, each improvement option redistributed the costs and benefits of all involved actors. In order to monitor the distributional issues, the Net Economic Output (NEO) of all actors was calculated.

Agricultural Water Use Systems: Some options lower and/or redistribute TVA in ways financially disadvantaging some actors. SDI investment costs would be recouped for many farms but exceed the greater yield and income from olive fields which are otherwise rain-fed. In the super-intensive scenario (CS2), combining three different eco-innovations, the higher TVA benefits all actors except olive farms.

Urban Water Use Systems: TVA redistribution may depend on political decisions. In CS3 Sofia the NEO of the water operator could increase from renewable energy, but the distribution has unpredictable, politically-contingent rules and potential conflict, e.g. as regards selling surplus electricity to the grid. For some eco-efficiency improvements in CS4 Zurich, the NEO of the water operator would decrease but could shift the loss to water users through higher prices. Households investing in water-saving appliances would have increased NEO under current prices, but again the water operator could raise prices to compensate.

Industry Water Use Systems: In the cogeneration plant (CS6), a few options would increase TVA, with various redistributions of TVA. Heat buffers would increase the gas supplier's NEO; heat-only boilers shift NEO from the heat producer to the gas supplier. Pre-heating potable and installation of micro CHP water would increase the NEO for domestic consumers and energy retailer.

For some options, the investor company would gain from the greater TVA, while the WWT operator would have economic losses (CS7, CS8). For the textile-dyeing process, several options would increase TVA and eco-efficiency for all indicators; but NEO may rise or decline for the investor company, depending on its characteristics (CS5).

2.3 Prospects for adopting eco-innovations

2.3.1 Organisational responsibilities

Decision-making for optimal meso-level eco-efficiency implies that economic and environmental aspects will be considered together in organisational decisions. Such improvements depend on shared responsibility among stakeholders, both within and across organisations. Eco-innovation depends on parallel socio-institutional innovation (Rennings, 2000), including broader assessments and responsibility. According to the World Business Council for Sustainable Development:

> *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).*

As an institutionalized form of meso-level analysis and cooperation, for example, the Water Framework Directive requires water-basin plans with integrated assessments (EC, 2000). This may provide a useful analogy for a meso-level eco-efficiency analysis and stakeholders' joint responsibility. However, responsibilities are generally fragmented across stages of the water-service value chain, even within the same organisation.

Comparative results

In most EcoWater case studies, improvement options had rarely been discussed in multi-stakeholder fora, nor even amongst all relevant parts of the main organisation under study. Irrigation water supply is managed by a Water Users' Organisation whose responsibility ends at the farm gate, though it offers advice to its farmer-members (CS1, CS2). As an exception, one large company's environmental targets were incorporated into investment decisions (CS7 Arla). Likewise an SME's Director considers all those issues together, partly because it has few specialised staff (CS5 Biella).

Each case study stimulated actors' interest in meso-level comparative assessments of improvement options. Such comparisons helped to structure workshops for multi-stakeholder discussions (see section 3) and stimulated discussion within organisations as well as among them. Such broader considerations have greater impetus and potential continuity during a decision-process on investment priorities.

2.3.2 Multi-stakeholder discussions

According to the Roadmap to a Resource Efficient Europe,

> *Exchanging information on routes to resource efficiency between partners in value chains and across sectors, including SMEs, can prevent waste, boost innovation and create new markets… (CEC, 2011b: 6).*

Beyond simply information exchange, sustainability transitions depend on mutual understandings. In dealing with current structures, an actor needs knowledge of other actors – their interpretive schemas, capacities, normative expectations, etc. An external agent such as a researcher can facilitate actors' development of such necessary knowledge, e.g. through multi-stakeholder workshops (Grin et al., 2010: 273).

Future-visioning exercises have become a commonplace means to express good intentions for environmental sustainability. Moreover, such exercises can provide conditions for change – more so if linked to demonstration projects of environmental improvement. Transition scenarios are meant to be inspiring, especially if developed by front-runners operating independently of the dominant regime. Socio-technical scenarios can shape stakeholders' expectations, formulate transition routes and develop strategies to realise them. To envisage different futures and identify influences on investment decisions, a standard method is to identify PESTLE factors (Political, Economic, Social, Technical, Legal and Environmental). A similar tool is called STEEEPA, focusing on Social, Technical, Economic, Environmental, Educational, Political and Aesthetic aspects (Van der Heijden, 2005: 183).

Multi-stakeholder discussions: comparative results

Along the above lines, the EcoWater workshops helped stakeholders to exchange knowledge and better understand each others' perspectives. As front-runners for eco-innovation within their own sector, the main organisations envisaged further improvements.

Alongside assessing the relative benefits and trade-offs of various options for eco-innovation, each case study also investigated prospects for their adoption. This inquiry involved interviews with key actors, multi-stakeholder discussions, and analysis of drivers and barriers. The analysis was carried out informally with stakeholders and/or in a formal exercise.

The project devised a PESTLE table-template with standard categories of factors which could be drivers and/or barriers of innovative practices (D1.7: 18-19). PESTLE analyses were carried out in various ways – by the study team alone, in one-to-one interviews, jointly at a multi-stakeholder workshop, etc.

From the results of multi-stakeholder discussions, it was obvious that the same factor can be a driver or barrier, depending on its precise form and context; so inquiry should be specific about both aspects. Case studies had significant differences in drivers and barriers of eco-innovation.

Agricultural cases

The focus has been relationships between farmers, their organisations and wider policies. In both case-study areas, farmers lack a knowledge-system to know their current water-use efficiency, crops' water needs, alternative agronomic methods (e.g. organic cultivation methods), etc. Consequently farmers do not achieve the full benefits of innovative practices, thus potentially deterring their further adoption.

<u>CS1 Sinistra Ofanto</u>: In the context of anticipating future water shortages, stakeholders expressed interest in further eco-innovation at farm level, especially to avoid the need or incentive for groundwater abstraction in dry summer periods. The water users' organisation advocated wastewater reuse, which faces many obstacles. This hypothetical solution could marginalise more feasible options and displace responsibility for farm-level improvements.

CS2 Monte Novo: Anticipating a water-price rise towards full-cost recovery, farmers anticipated economic difficulties for more water-demanding crops, especially maize. They sought means to make best use of their past technological investment, especially through better information systems to anticipate meteorological conditions.

Urban cases

CS3 Sofia: The workshop focused on two options for the water operator to recover energy and analysed potential barriers to such investment, e.g. a legislative gap in assigning the economic benefits.

CS4 Zurich: Workshop participants were already familiar with various individual options for improvement; they wanted wider perspectives to assess system-wide improvements. According to the case-study team's analysis, householders could have increased NEO by investing in water-saving devices which save energy as well as water, but their prices may be too low to incentivise such investment.

Industry cases

As a general pattern, multinational companies have relatively greater capacities and internal incentives for technological improvement, often going beyond legal requirements. They see EU legal-environmental frameworks, including future trends towards more stringent criteria, mainly as facilitators or drivers. By contrast, many SMEs see those frameworks as barriers. This general difference has been reported in Europe-wide studies (EIO, 2011, 2012) and is illustrated by the EcoWater case studies.

CS5 Biella: Although the workshops attracted only (two) textile-dyeing SMEs, the discussion helped to share their perspectives on eco-innovation and to identify common difficulties. They identified significant barriers to eco-innovation, e.g. legal-environmental frameworks, a general economic decline of Biella producers (partly due to cheap imports) and thus potential difficulties to repay loans.

CS6 Cogeneration: As a focus of the workshop, a thermal network (especially district heating) otherwise had little attention from stakeholders. According to the discussion, this option would depend on a long-term policy commitment, e.g. to match the price of district heating with heat from natural gas, but such a commitment seemed elusive in the local context. This insight emerged from a group exercise developing an influence diagram of drivers and barriers.

CS7 Arla: The workshops facilitated multi-stakeholder discussion on comparing options for eco-innovation, within and among dairies, and on better sharing information across the water-service value chain. Arla Foods has seen current policies generally as drivers for eco-innovation. Some dairies foresee benefits of technology for water recycling and reuse, but its adoption would depend on an EU-wide regulatory change permitting such usage.

CS8 Volvo: This company too sees current policies mainly as drivers for eco-innovation. It foresaw numerous benefits from adoption of a new chemical process, but this may be impeded by unclear BAT criteria in EC regulations, so these warrant an update.

2.3.3 Policy and institutional implications

The Europe 2020 strategy includes 'Resource efficient Europe', aiming to decouple economic growth from the use of resources, alongside 'resource efficient technologies' (CEC, 2010a: 4). According to *A Resource-Efficient Europe*: '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'. For example, 'stricter environmental targets and standards which establish challenging objectives and ensure long-term predictability, provide a major boost for eco-innovation' (CEC, 2011a: 2, 6).

The 7th Environment Action Programme calls for measures to 'further improve the environmental performance of goods and services on the EU market over their whole life-cycle' (EC, 2013a, 2014). Greater resource-efficiency 'will ease pressure on the environment and bring increased competitiveness and new sources of growth and jobs through cost savings from improved efficiency, the commercialisation of innovations and better management of resources over their whole life cycle (EC, 2014: 8). Implementation 'shall be informed by the European Environment Agency's indicators on the state of the environment as well as indicators used to monitor progress….' (ibid: 11; EEA, 2014).

The Environment Action Programme further emphasises the need for indicators to monitor change:

> *Several key concepts, including green economy, resource efficiency, sustainable consumption and production and circular economy, are increasingly being discussed and used in Europe, and imply considerable changes in the way production and consumption are organised. Indicators have a crucial role in tracking progress towards the implementation of these policy concepts (EEA, 2014: 21)*

The EEA report applies indicators to changes in entire economies or industries, but without identifying their basis at production sites. Such changes (actual or potential) can be identified through indicators in meso-level system interactions, as in the EcoWater case studies.

Resource-efficient innovation has numerous drivers and barriers, which have been identified on a general industry-wide basis (DG Communication, 2011; EIO, 2011, 2012). EcoWater case studies identify drivers and barriers in specific meso-level contexts. According to the *Roadmap to a Resource Efficient Europe*, an important aim is to enhance dialogue. Policy makers, at EU, Member State and regional level, need to engage in active discussion with business and civil society about the policy conditions necessary to overcome the barriers to resource efficiency (CEC, 2011b: 20).

The EcoWater project explored multi-stakeholder perspectives on eco-innovation for resource efficiency, as a basis to identify drivers, barriers and policy implications.

Policy implications: comparative results

In each case study, specific policy frameworks seemed most important in facilitating or impeding eco-innovation, especially the most eco-efficient options. This analysis helps to identify what policy changes would be helpful. These could be relevant at EU, national and/or local level.

Agriculture

Farm Advisory Service: In the case-study areas, farmers lack adequate knowledge to know the current water-use efficiency and thus incentives for adoption of more resource-efficient technology. Amongst various innovative options for future improvements, the greatest eco-efficiency increase would come from replacing chemical with organic fertiliser, especially if combined with other environmentally favourable techniques such as low-till. Conversion to organic pastures and agri-products would offer even greater environmental benefits. All these improvements depend on farmers' knowledge and skills. A Farm Advisory Service would not achieve those aims simply by referring farmers to specialist advisors (CEC, 2010: 8). To achieve its aims, a Farm Advisory Service needs to facilitate a farmers' knowledge-exchange system (Levidow et al., 2014). Regional authorities should take responsibility to build on and expand current initiatives, with support from DG Agriculture's programme for a Farm Advisory Service. A farmers' knowledge-exchange system could be developed through the agricultural extension service and/or the water users' organisation, including training workshops.

CAP subsidies: In both case-study areas, farmers' incomes are highly dependent on the CAP, whose greening agenda would therefore be an effective way to promote more resource-efficient practices, e.g. through Ecological Focus Areas (DG Agriculture, 2013; EC, 2013b, 2014). Under the CAP 1st pillar, national and regional authorities can incentivise organic fertilisers; criteria could emphasise improving soil fertility, improving biodiversity and avoiding agrochemicals. But farmers face bureaucratic difficulties to participate in the CAP.

Water scarcity: EU policy documents assume or imply that water-scarcity problems could be overcome simply by more water-efficient technology (CEC, 2008b; EP, 2008), yet their adoption and efficacy depend on a broader knowledge systems linking farmers with each other and various experts.

Urban

In the urban case studies, household water use is the environmentally weakest stage, especially as regards energy and water use. Eco-efficient solutions are available in various resource-efficient domestic appliances. But their adoption would reduce the income of the water operator, which therefore has no incentive to encourage householders. Resource-efficient domestic appliances have no clear basis for stakeholder discussions, nor an obvious policy framework; so this is an institutional gap.

As a different issue, Swiss water operators have new statutory obligations to remove micropollutants and recover phosphorous. The former in particular imposes great resource burdens through energy inputs. The EcoWater method provides ways to evaluate different options for fulfilling those obligations.

Industry

For the two multinational companies (Arla and Volvo), eco-innovation may be impeded by a regulatory gap in the BAT criteria of the EC Industrial Emissions Directive, as below. Other cases revealed different kinds of policy gaps or barriers.

CS5 Biella textiles: SMEs need strategies to deal with competition from cheap imports, often by fellow Italian companies. They need assistance to expand long-distance quality markets, as an eco-innovation complementing capital investment. The latter needs long-term loans which may be difficult to obtain, and whose repayment faces uncertainties from the industry's general decline.

CS6 Cogeneration: District heating offers multiple benefits for resource efficiency, but the investment depends on a long-term policy commitment, e.g. to match the price of district heating with heat from natural gas.

CS7 Arla: Water recycling and reuse would depend on an EU-wide regulatory change in the dairy-industry BREF to permit such usage.

CS8 Volvo: A new chemical process (silane-based technique) may be impeded by unclear BAT criteria in EC regulations, so the corrosion-protection BREF warrants an update.

2.4 Conclusions: methodological implications and wider relevance

The EcoWater project developed a method for selecting and applying eco-efficiency indicators to compare various improvement options with the baseline situation at the meso level, also known as a systemic approach. The meso-level focus enabled analysis of interactions among heterogeneous actors in water-service systems, firstly in the current situation and then for potential eco-innovations.

The EcoWater method was applied to eight case studies spanning three sectors (agricultural, urban and industrial). Each case made methodological judgements about several aspects: defining the meso-level system, selecting relevant indicators for the economic and environmental components of eco-efficiency, obtaining and analysing data necessary for each indicator, identifying the environmentally weakest stage, addressing that stage with eco-innovation options and combining some options for optimal meso-level improvements.

This report has compared the methodological judgements and their results across the case studies. The report is structured around three main methodological aspects, which arose in iterative ways, not always in a linear sequence. Each aspect has methodological implications, as follows.

1. **The meso-level system**, explaining the main concepts, as a basis for comparing: the sectoral contexts for eco-innovation, the specific focus for upgrading each water system, and judgements on the meso-level system boundaries in each case study.

Starting from a sector in a geographical area, each case study sought a more specific focus for feasibly developing the EcoWater method when the project began. Organisations most willing and able to cooperate with the project had already made significant investment in innovative resource-efficient practices and were considering extra improvements. Impetus came from their environmental policies and/or from external drivers such as future higher costs and resource scarcity, often going beyond current legislative requirements. So each case represents the sectoral potential in a symbolic sense, rather as an average or typical example which would have weaker prospects for improvement.

Not initially obvious in the case studies, the meso-level boundary was sometimes clarified or expanded later in the study. Each case study started from a large-scale meso level, eventually choosing a small-scale focus as a window into potential improvements, e.g. a specific process or site within a larger system. The meso-level boundary and indicators should encompass effects of eco-innovations to address the environmentally weakest stages, whose sources can be identified more easily in the system's foreground. In general these sources were clarified in a later methodological step (next sub-section), so the method was iterative, sometimes reconsidering previous steps in the light of later assessments.

2. **Eco-efficiency assessments,** estimating the most relevant eco-efficiency indicators for the baseline scenario, with distinctions between the foreground and background system, selecting technologies which may upgrade the meso-level system, by exploring trade-offs among various aims, and redistribution of total value added among actors in the water-service value chain.

   Each case study explored eco-innovations, i.e. innovative practices which bring economic and environmental benefits. Some upgrade the production process and/or the product through higher value. Although these improvements may change or add a technology, they can take other forms, e.g. by substituting organic fertiliser or herbal dyes for chemical ones, or linking waste heat with residential buildings.

   As the case-study comparisons reveal, improvement options are case-specific, e.g. dependent on the context, the environmentally weakest stage, the potential for system improvement and data availability. In each case the general method was adapted, especially so that the meso-level boundary encompasses potential effects of the eco-innovations being evaluated. The meso-level analysis adds information about effects beyond a micro-level focus on an organisation's internal processes, in ways reducing or complicating the apparent benefits at that level.

   In each case study, few options would improve all environmental indicators, increase total value added (TVA) and financially benefit all actors in the meso-level value chain. Selecting the most eco-efficient options entails tensions and trade-offs among various objectives, e.g. between micro versus meso levels, economic versus environmental aims, different resource burdens, process stages, economic beneficiaries versus losers, and short versus long-term return on investment, economic predictability, etc.

   As a pervasive tension, each improvement option redistributed the total value added (TVA) from using the water. To identify redistribution effects, the TVA was analysed according to the net economic output (NEO) of each value-chain actor. For the most eco-efficient options, the investor in eco-innovation can either gain or lose NEO, depending on the rationale and context.

In all those ways, the results complicate eco-innovation as a win-win strategy. The potential to optimise meso-level eco-efficiency, alongside various trade-offs, highlights the value of sharing stakeholders' different understandings through meso-level discussion, in ways appropriate to each specific context.

3. **Prospects for adopting eco-innovations**, comparing organizational responsibilities for meso-level improvements through eco-innovation, multi-stakeholder discussions illuminating meso-level interactions and improvement options, and policy implications for facilitating such improvements.

   Decision-making for optimal meso-level eco-efficiency implies that economic and environmental aspects will be considered together in organisational decisions. The improvements depend on shared responsibility among stakeholders, both within and across organisations. However, responsibilities are generally fragmented across stages of the water-service value chain, even within the same organisation.

   In most EcoWater case studies, improvement options had rarely been discussed in multi-stakeholder fora, nor even amongst all relevant parts of the main organisation under study. Each case study stimulated actors' interest in meso-level comparative assessments of improvement options. Such comparisons helped to structure workshops for multi-stakeholder discussions and stimulated discussion within organisations. Such broader considerations have greater impetus and potential continuity during a decision-process on investment priorities

   According to the *Roadmap to a Resource Efficient Europe*, 'exchanging information on routes to resource efficiency between partners in value chains and across sectors, including SMEs, can prevent waste, boost innovation and create new markets…' (CEC, 2011b: 6). EU and expert reports generally analyse such issues on a macro level, e.g. across an entire economy or industrial sector, thus neglecting meso-level multi-stakeholder interactions.

   Through the EcoWater case studies, multi-stakeholder workshops envisaged broader options for system improvements, evaluated their relative benefits at the meso level, and considered ways of optimising eco-efficiency for the meso-level system. By analysing factors which influence investment decisions, the discussions identified policy frameworks which may facilitate or impede eco-innovation, especially the most eco-efficient options. These policy implications are relevant at the EU, national and/or local level.

Concluding, in analysing and comparing the case studies, the story here has drawn on socio-technical perspectives for identifying dynamic interactions between societal, policy and technological change. This involves socio-technical dynamics amongst technology users, uses, functions, choices and design (Geels, 2004; Geels and Schot, 2007). The cross-case comparisons here illustrate a diverse range of socio-technical dynamics for adapting the general EcoWater methodology.

As shown by comparisons among diverse cases, the general method was robustly applied – to assess options for eco-efficiency improvements, to evaluate their relative meso-level benefits, and to facilitate multi-stakeholder discussion on optimising the system. So the method has wider relevance to any meso-level water-service system.

Although it has been developed with such a focus, the method also could be adapted to assess improvement options centering on other resource uses. Such adaptation would need to combine further conceptual and empirical analysis.

3 CS1. Sinistra Ofanto

3.1 Meso-level system

3.1.1 Eco-innovation context

Dating from the 1980s, the Sinistra Ofanto irrigation scheme is among the largest multi-cropped irrigated areas in Italy. It is located in Southeastern Foggia province within the Apulia region. Irrigation is crucial for the region's agricultural production and income. Nearly 18.5% of Apulia's agricultural area is under irrigation; consequently, irrigated crops have contributed 69% of the total value of regional agricultural production, recently quantified as 3.8bn Euros.

The study area is characterized by a high number of small land-holdings with intensive, market-oriented practices. The main crops are vineyards, olives, vegetables and fruit orchards (in descending order). The pedo-climatic conditions are favourable for intensive cropping, but profitable farming is strongly dependent on irrigation, due to the scant rainfall and its uneven distribution across the year.

The system is already equipped with modern technologies to deliver and use water efficiently. From the diversion structure on the Ofanto River, water is conveyed to the Capacciotti reservoir through concrete-lined canals and pipe conduits, along which the flow regulation devices are downstream-controlled, thus manually or automatically adjusted through calibrated control devices enabling Supervisory Control and Data Acquisition (SCADA). The Capacciotti reservoir supplies 7 concrete-lined storage and compensation reservoirs equipped with downstream-control flow regulation devices that adjust inflows and outflows to feed the district's piped distribution networks based on the downstream water demand.

PVC buried pipes comprise the open-branched distribution networks. Each sector's inlet has a control unit, equipped with flow and pressure metering-control devices. Water is supplied to farms on demand by means of multi-users' electronically-fed hydrants that control and regulate the deliveries, as well as the discharges demanded and thus flowing in the pipe distribution network. These help keep conveyance and distribution losses within 5-10% of the total water abstracted from the Ofanto River.

The Water Users Organization (WUO), Consorzio per la Bonifica della Capitanata (henceforth the CBC), is the main management agency for irrigation water. It is responsible for all the sequential steps of the agriculture water supply chain, i.e. abstraction, conveyance, storage, distribution and final water delivery to farm gates. Established in 1933 by a national law of public interest, the CBC is by statute a non-profit organization; it bears all the costs for performing its functions, and these costs are recovered through the water tariffs paid by farmers.

Although the main water supply is surface water, during recurrent water shortages farmers pump groundwater from medium-depth (100-150m) aquifers, especially since the late 1990s. Many farmers still perceive groundwater pumping as somewhat cheaper than metered water, even though the contrary was shown by economic analyses (e.g. Portoghese et al. 2013). Furthermore, studies found qualitative degradation of groundwater resources, most likely resulting from seawater intrusion into the coastal aquifer and to deep percolation of pollutants, such as fertilizers and pesticides, from intensive farming activities.

From the growers' standpoint, groundwater pumping aims to increase and/or stabilise the economic benefits of farming activities. Often farmers combine surface water and groundwater for various reasons such as to maximize crop yields and farm net benefit, or to minimize the seasonal water fees payable to the CBC, or to prevent yield reduction arising from high salinity in the groundwater during peak-demand periods. However, this conjunctive use of surface and groundwater is based solely on farmers' economic and technical considerations, regardless of environmental burdens such as aquifer depletion and degradation. Furthermore, fields close to the river banks are often irrigated by growers with water pumped out the river. In all these situations, return flows may result from run-off through the drainage networks, as well as from percolation through the soil profile, finally reaching the downstream reaches of the river, wetlands or the aquifer.

3.1.2 Eco-innovation upgrading as the case-study focus

Often Sinistra Ofanto farmers apply greater amounts of fertilizers than crops need. A common fertilizer, ammonium nitrate, contains up to 34% nitrogen; the more intensive irrigated farms can reach levels of about 350 kg/ha, associated with leaching eutrophication and GHG emissions in the atmosphere. Hence better placement and precision application, as well as slow-release formulations, can reduce N_2O losses from cropping. N_2O is a by-product of fuel combustion, so more efficient field-management practices (e.g., reducing mobile fuel consumption in motor vehicles) can reduce emissions.

A greater change would be to replace synthetic fertilisers. In southwestern Europe, the use of organic fertilizers has been increasing because of perceived environmental advantages. Conversion to organic pastures and agriculture could mitigate 40% of agriculture's GHG emissions, rising to 65% when combined with zero tillage. Organic farming could reduce irrigation needs by 30-50%. Lower tillage also saves energy by reducing direct energy consumption and CO_2 emissions from fossil fuel usage (IFOAM-EU, 2011).

Along those lines, Sinistra Ofanto farmers with low-income cropping patterns (i.e. wheat) have sought to increase the product quality by shifting from traditional to organic agriculture. Organic farming is a pioneer in preserving water quality, avoiding synthetic fertilizers and effectively managing water sources by building up the soil and increasing its resilience to extreme weather events.

3.1.3 Meso-level boundaries

The agricultural water system considers the entire life cycle of water from its source as a natural resource to the final use in agricultural fields. The main stages in the system are: the water supply system (conveyance canal and reservoirs), the distribution systems (pumping plants, reservoirs and farm network infrastructures) and the final stage (fields) where water is used for agricultural production.

The foreground includes all the stages along the water value chain (the water abstraction and supply stage, the water distribution systems and the irrigation zones/final water use stages) where resources are used. The background subsystems include the resource production processes (nitrogen and phosphorus based fertilizer, electricity and diesel).

Directly involved actors: water-users' organisation (CBC) in charge of water storage, delivery and distribution; farmers' associations which manage on-farm water supply.

Indirectly involved actors: regional auhorities dealing with CAP subsidy and criteria; regulatory authorities; Apulian Regional River Basin Authority, responsible for monitoring and controlling water-resource use and management.

3.2 Eco-efficiency assessment

3.2.1 Baseline assessment

Arising from the water-use stage, the greatest resource burdens are:

- Freshwater resource depletion due to irrigation, excessively depleting aquifers (in the foreground part of the system);
- Climate change impact due to direct emissions from fertilizer and fuel consumption (mainly from foreground);
- Eutrophication of groundwater and surface water due to NO_3^- and PO_4^3 leaching (mainly from foreground).

As in any agricultural system, the environmental impacts are dependent on the cropping pattern, water availability and management, i.e. yield production. In general, the economic benefits increase with greater irrigation water supply and the more commercial cropping patterns. However, irrigation increases the environmental burden because greater water service related materials and supplementary resources are used. Hydrological conditions play a relevant role because more precipitation usually means (at least for winter crops) lower irrigation requirements and therefore less consumption of resources. Nevertheless, in a dry year, with annual precipitation of around 400mm or less, several problems could occur for economic and environmental sustainability, including aquifer depletion (D2.2: 41-42). TVA varies according to crop prices and increasing water prices; the latter were fixed by law and so are more predictable.

3.2.2 Technology options comparison

Farm activities generate various pressures on land and water resources, including quantitative depletion and qualitative degradation, especially biodiversity loss in farmland and in the natural environment. This harm has several sources: (i) intensive farming and tillage practices, (ii) fertilisers and pesticides application on cultivated fields, (iii) water abstraction from the Ofanto River, (iv) return flows of degraded water to downstream wetlands and aquifers, (v) over-drafting of groundwater, (vi) salinity build-up in cultivated soils, (vii) energy consumption for water pumping, and (viii) increased CO_2 emissions from the energy usage related to pumping, transport, machinery, etc.

Consequently, technology options were sought for the following improvements (D2.2: 42):

- More efficient irrigation technologies that will reduce energy and fresh water consumption on the agricultural use level.
- Decrease of resource burdens from fossil fuel usage (climate change indicator) and electricity production (human, terrestrial and aquatic ecotoxicity indicators);
- Reduction of fresh water depletion indicator;
- Reduction of the discharge of pollutants due to the use of less toxic chemicals (fertilizers) which will improve the “eutrophication” and “acidification” eco-efficiency indicators.

Specific technologies

On the basis of a broad stakeholders’ consultation, the case-study team compiled a list of advanced water and energy technologies and farm-management practices. The eco-efficiency of the baseline was compared with six different options:

1. Surface-drip irrigation instead of micro-sprinklers (for artichoke, olives and orchards), to be adopted for greater on-farm irrigation efficiency and water-saving, while keeping wheat rain-fed.

2. Subsurface drip irrigation (SDI) to be adopted for several crops (artichoke, olives, table grapes and orchards, while keeping wheat rain-fed), in order to improve on-farm irrigation efficiency and water saving.

3. Substitution of on-farm diesel engine pumps with electrical variable-speed pumps (for water abstraction from the aquifer and from the river and then for water delivery and on-farm irrigation).

4. Substitution of on-farm diesel engine pumps with solar-powered pumps (instead of previous option).

5. Application of smart (remote) technologies for monitoring of soil-plant-atmosphere continuum and precise on-farm irrigation management.

6. New water-pricing policy with an increased annual water supply; this strategy would be applied at the water distribution stage.

Comparative results:

Water-saving irrigation technologies generally maintain the same eco-efficiency as the baseline, due to a slight increase of environmental performance alongside greater costs.

By using surface-drip irrigation, several environmental indicators would be improved, but seven eco-efficiency indicators would decline because the emissions reduction is outweighed by the high investment cost.

SDI performs better than surface-drip irrigation (and the baseline) through less evaporation, lower irrigation-water use per unit area, higher yield and higher income.

Electric variable-speed pumps save water but negatively impact several indicators (human toxicity, acidification, terrestrial ecotoxicity, respiratory inorganics and photochemical ozone formation), due mainly to increased electricity consumption.

Solar pumps would increase eco-efficiency for several environmental indicators – climate change, fossil fuel depletion and mineral depletion – which result mainly from diesel combustion in the foreground and inputs' life-cycle production from the background.

As a general pattern, eco-efficiency decreases mainly for indicators whose environmental burdens arise mainly from background processes*;* these are less easily improved by farm-level innovation and are worsened by fossil-fuel or electricity consumption (D2.4)*.*

Combined options

After assessing each technology separately, a combination was assessed (solar-powered pumps, subsurface drip irrigation and smart irrigation technologies), in two different scenarios. The 'super-intensive' scenario applies the three technologies more widely than the 'low-intensive' scenario. The former showed a much greater eco-efficiency increase for all environmental impact indicators considered in this study, due to higher TVA and better environmental performance, especially for climate change, fossil fuel depletion and mineral depletion (see Figure 4; D2.4).

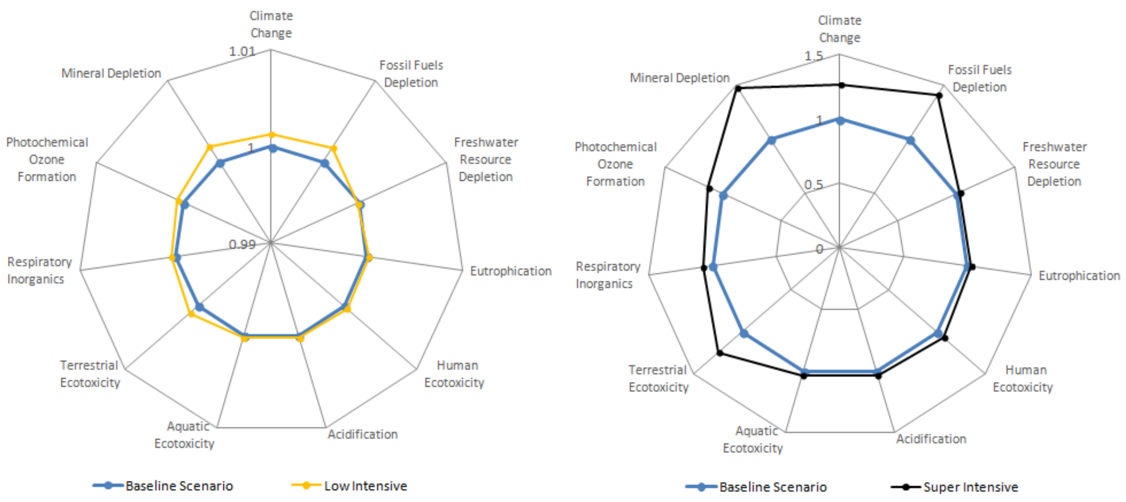

Figure 4 Eco-efficiency comparison of low-intensive and super-intensive scenarios

Distributional Issues

Subsurface drip irrigation (SDI) would generally increase yield, income and TVA. But NEO would decrease for olive farms, which are predominantly rain-fed and low income; the greater income would be outweighed by the high-cost technology investment (D2.4: 50). This illustrates the specificity of outcomes.

3.3 Prospects for adopting eco-innovations

3.3.1 Influences on adoption

Responsibilities: As an irrigation service provider, the CBC is composed of irrigation service users, i.e. farmers. In performing its daily activities, the CBC attempts to reconcile objectives which may be in conflict. Its technical and administrative choices aim to achieve high water-distribution efficiency in order to maximize the economic benefit to farmers. It aims to improve water distribution and use – at the farm level, through an effective operation of the delivery network, and at field and crop level through the technical support to growers aiming at improved water management skills. Technical support to farmers was effective in the 1980s-90s but has declined in the last decade, due to WUO budget constraints and lower revenues from Italy's farm activities. The CBC takes no responsibility for practices beyond the farm gate.

Drivers and barriers: According to interviews with farmers, the drivers for adopting innovation technologies were: a) the increase of water demand due to expansion of command area, b) water shortage due to change in precipitation patterns and c) water-delivery restriction imposed during peak-demand periods. Recently there has been a trend towards adoption of resource-efficient technologies; but there are several disincentives, e.g. high cost of labour, market price volatility and high initial investment cost.

Education: Farmers are not always well informed about innovative practices such as resource-efficient technologies and organic methods. This barrier can reduce their adoption and effectiveness when adopted, thus perhaps deterring other farmers. In the Sinistra Ofanto case, the Consorzio per la Bonifica della Capitanata (CBC) has been serving as a farm advisory service, especially for water availability, weather monitoring, water demand estimation and recommended water application rates. In recent years, in the province of Foggia, the farmers have formed small farm unions where they share their knowledge and experiences.

3.3.2 Multi-stakeholder discussions

Several technology options were presented at the EcoWater project workshop, held in the case study area and attended by diverse stakeholders and experts involved in the Sinistra Ofanto water-system value chain. They were asked to share their visions about water management in the area. The discussion identified several issues, emphasising the need for measures to protect groundwater.

As many comments highlighted, in the last three decades contradictory interests have generated conflicts over water allocation and use. Surface-water availability for agricultural use has been reduced by several factors: expansion of the command areas, incentivised partly by irrigation systems and by regional policies; greater water demands of the municipal, industrial and tourist sectors; and adverse environmental-climatic changes. Participants mentioned several solutions, in particular:

- Monitoring and control of water use should be strengthened throughout the Apulia region, especially in the study area, in order to avoid aquifer over-exploitation and uncontrolled withdrawals from water courses;
- Deficit irrigation management, already practiced in the study area by some innovative growers, offers a feasible option to enhance water-use efficiency and productivity; and, finally,
- Share of personal experiences and knowledge among farmers in order to help others to use irrigation water in a sustainable, efficient way (D6.1).

In addition CBC representatives emphasised the importance of using non-conventional water sources as an additional supply, especially the re-use of treated wastewater (TWW) as a valid alternative to aquifer exploitation for irrigation purposes. TWW re-use has several barriers: stringent quality criteria set by regulations for water reuse in agriculture; the high cost of treatment and water conveyance from the treatment plants to agricultural areas; and inadequate research dissemination, even disinformation; and reluctance by farmers. Consequently, TWW re-use should be fostered by several means – lowering the water-quality restrictions, installing the latest technologies available on the market for wastewater treatment to reduce costs of treatment plants, and broadly disseminating research findings to growers, especially through extension activities and farmers' advisers – according to the CBC representatives (D6.1). No stakeholder raised concerns about aquifer characterisation, safe-yield assessment, groundwater recharge or agrochemicals' fate in soil and aquifers, or farm-level performance assessment of agricultural water management practices.

3.3.3 Policy and institutional implications

As emerged during the stakeholder discussion, some future visions may be based on doubtful assumptions. In particular the CBC staff and farmers' representatives assumed that Sinistra Ofanto farmers already achieve high irrigation and water-use efficiency, simply on grounds that they use microirrigation methods. From this assumption, there would be little scope or incentive to growers for further improvement in farm-level water management. The CBC has been serving as a farm advisory service, especially for water availability, weather monitoring, water-demand estimation and water-application rates. But the advice has no external validation and has no systematic means for knowledge-exchange.

From CBC technical reports over at least a decade, no recent information is available on whether the farm irrigation systems are properly designed, installed, operated and maintained – nor on whether irrigations are adequately scheduled and conducted by growers. Likewise the CBC has not recently evaluated irrigation systems for the farmers' actual application efficiency and distribution uniformity, nor the water-use efficiency for the various crops and irrigation methods, on the basis of quantitative measurements. Agricultural extension activities have been significantly limited in the last decade by budget constraints. So the CBC lacks an empirical basis for its efficiency assumptions about current performance of on-farm water management. In all those ways, the CBC's practical responsibility ends at the farm gate (Levidow et al., 2014).

From the above analysis, there follow several recommendations:

- Farmers' incentives: Create incentives for farmers to adopt the best (environmentally friendly) management practices at farm level. Solution should be sought in water-energy saving technologies combined with organic types of fertilizers and adoption of zero-tillage where possible.
- Finance: Improve access to loans for those willing to invest in eco-efficient practices, especially for innovations with long development times.
- Education: Design an effective information and education program on adoption of eco-efficient technological solutions at various scales. Sponsor targeted workshops and roundtables to promote technology demonstrations.

- Agricultural extension service: Technical assistance is needed to deal with large-scale water delivery issues and farm-specific situations. Farmers need a knowledge-exchange system for knowing their current water-use efficiency, optimising the application of current technologies and incentivising further improvements.
- CAP: Increase the flexibility for participants in commodity programmes to respond to market signals and adopt environmentally sound production practices and systems, thereby increasing profitability and enhancing environmental quality in compliance with EU regulations (D2.4).

4 CS2 Monte Novo

4.1 Meso-level system

4.1.1 Eco-innovation context

Since 2009 the Monte Novo irrigation perimeter has provided water for irrigation to an area of more than 7800ha. This perimeter is integrated into the Alqueva Multipurpose Project – the Empreendimento de Fins Múltiplos de Alqueva (EFMA). The 1993 EFMA plan combined a reservoir, hydroelectric dam and irrigation networks, thereby helping to justify Portugal's claim on the water. The project aimed to promote the development of a poor, deprived region through irrigated agriculture, electricity production and tourism.

By using cheap water from the Alqueva dam, some Alentejo farmers were expecting to capture greater payments from the CAP 1st pillar. So they opposed mid-term reforms decoupling such payments from production levels; so did the Portuguese government (Costa, 2003: 26).

Irrigation delivery service is provided by the public company EDIA (Empresa para o Desenvolvimento das Infrastruturas de Alqueva), the agency responsible for the Alqueva project development and exploitation. Water is abstracted from the Alqueva reservoir and transported through a network of canals and ducts, from primary network to secondary network through hydrants to farmers. Within the larger Alqueva project, the Monte Novo irrigation perimeter is located in Alentejo district, near Évora municipality. The perimeter provides water for irrigation to an area of at least 7800 ha, while the Alqueva Project will have a total 115,000 ha expected capacity by 2015.

In the Guadiana region including Monte Novo, the agricultural sector has 10% of the region's GVA and about 15% of the jobs; average farm size is large (55 ha). These characteristics, associated with the high proportion of farmers in a company structure, indicate the region's high potential to develop agricultural activities, especially with the full operation of the Alqueva project. But its agricultural activities have a very low competitiveness and a low productivity per unit area; incomes are greatly supported by public subsidies, which comprise about 65% of the total gross margin (ARH-Alentejo, 2011).

In the study area, the major irrigated crops are olives, maize, arable crops (mostly pasture) and horticultures (mostly tomatoes). Farm size ranges from less than 50 ha to more than 500 ha. The largest areas belong to important multi-crop farms, such as the ones owned by the Fundação Eugénio de Almeida (FEA), or the olive farms owned by Olivais do Sul (ODS); together they comprise more than 30% of the irrigated area in Monte Novo irrigation perimeter.

Fertilisers and pesticides are applied to all crops, especially tomatoes and maize. Greater irrigation stimulates run-off, leach-outs of fertilisers and pesticides and soil erosion. Together these practices reduce soil organic matter, soil fertility and its capacity to retain water, in turn increasing potential irrigation inefficiencies and need for better water management for the same cultivation level as before.

In 2009 the WUO Associação de Beneficiários de Monte Novo (henceforth ABMN) was established, representing all farmers connected to the Alqueva water distribution system from EDIA. According to the regulatory Decree Law 84/82, the Association has formal recognition by the Ministry of Agriculture, Trade and Fisheries. The ABMN has the role to promote the administration of constructing the hydro-agricultural development. Nonetheless EDIA has carried out the management and operation of the irrigation perimeter, as well as the investments in constructing the irrigation network.

With its geographical topography and high elevation, the Alqueva scheme was an expensive investment (Costa, 2003), especially relative to the small number of farmers who initially joined the scheme. This arrangement resulted in a high unit cost for the water supply. This has high political-economic stakes, given that full-cost recovery of irrigation systems is required by the Water Framework Directive (EC, 2000).

Given those high costs, full-cost recovery would impede a full transition from rain-fed to irrigated agriculture. To attract farmers into the scheme, a 2010 law set the initial water price at only 30% of full cost. This initial price shifts more of the total cost onto the supplier, while incentivizing maize cultivation, which demands relatively large amount of water but gains a higher market price.

4.1.2 Eco-innovation upgrading

The study team assessed various options for lowering input demands (of energy, water, agrochemicals) or for increasing farmers' income per unit water used (EcoWater, 2012), in two main categories as follows.

At the irrigation perimeter level, i.e. the distribution network:

- Tiered volumetric water tariffs according to actual water use by growers;
- Tiered water tariffs according to timing of withdrawals and energy costs, e.g. lower rates at night-time; and
- Pressure head delivery.

At the farm level:

- Drip irrigation, reducing water evaporation (especially relevant to maize);
- Sub-surface drip irrigation, minimizing soil evaporation and facilitating mechanical weed-control or conservation tillage or minimum-tillage methods (especially relevant to vineyards);
- Super-high density olive orchards;
- Variable-irrigation practices, e.g. through regulated deficit irrigation; and
- Alternative crops demanding less water.

4.1.3 Meso-level boundaries

The meso-level system includes the following stages: (i) the primary network, which corresponds to water abstraction in the Alqueva reservoir (main storage reservoir of the system), elevation and water transport to the secondary networks; (ii) the secondary network, which includes the regulating storage made through several reservoirs, the elevation stage and the water distribution to the different irrigated farms considered; and, (iii) the farmers (users) in the Monte Novo case study, which are represented by means of the most representative crops in the area (maize, olives – both intensive and super intensive – and pastures).

Directly involved actors:

- EDIA (Empresa para o Desenvolvimento das Infraestruturas de Alqueva), responsible for the management and development of the Alqueva multipurpose project, including the operation of primary and secondary irrigation network where the Monte Novo irrigation perimeter is located;
- Water users' organisation ABMN (Associação de Beneficiários de Monte Novo), representing all the farmers which are connected to the Alqueva water distribution system from EDIA;
- Farmers that benefit from the irrigation networks

Indirectly involved actors: CAP regional authority, environmental authority, COTR (Centro Operatio e Técnicas de Regadio), a technical advisory body.

4.2 Eco-efficiency assessment

4.2.1 Baseline assessment

Economic indicators

The cost estimation originally included only costs for water, energy and fertilizers (D2.2). The baseline scenario later added costs for seeds, labour and equipment and other costs, which include an estimation of investment cost amortization (D2.4: 56).

Environmental indicators

Foreground contribution: Freshwater resource depletion expresses the water abstraction to satisfy the agricultural requirements at the farm level; and eutrophication represents the use of phosphorous and nitrogen fertilizers in agriculture.

Background contribution from electricity and fertilizer production (75%) includes high environmental impact for climate change, acidification, respiratory inorganics, terrestrial ecotoxicity, photochemical ozone formation, minerals depletion and fossil fuels depletion indicators (D2.4: 58).

Arising from the water-use stage, the greatest resource burdens are the following:

- Freshwater resource depletion, due to high amount of water abstracted for irrigation;
- Eutrophication, due to the use of fertilizers (nitrogen and phosphorus) and run-off;
- Fossil fuel depletion and human toxicity due to energy production in background.

4.2.2 Technology options comparison

Individual options

Five technology options were evaluated, at first separately.

1. Water saving through Regulated Deficit Irrigation (RDI) for olives, maize and pastures. This technology is assessed separately for “Low Pressure” and “High Pressure” areas.

2. Decrease of fertilizer use through the introduction of sludge from WWT plants of the area. This technology is evaluated for both “low pressure” and “high pressure” areas.

3. Decrease of fertilizer use through the introduction of organic compounds appropriate for biological agriculture. This technology is implemented for both “low pressure” and “high pressure” areas.

4. Improvement of the irrigation efficiency through the adoption of subsurface drip irrigation instead of drip irrigation for maize and olives. This technology is implemented for both “low pressure” and “high pressure” areas.

5. Reduction in water costs by re-scheduling irrigation to periods during which the energy price is lower.

Eco-efficiency comparison for all technology scenarios

Application of the organic fertilizers to maize offers great benefits in increasing the indicators for eutrophication and aquatic ecotoxicity, due to lower use of chemical fertilizers.

WWT sludge application offers a slight improvement in eco-efficiency in various indicators.

Regulated Deficit Irrigation technology offers a high improvement of environmental performance for all the crops due to the reduction in water and energy consumption.

Subsurface Drip Irrigation technology does not increase eco-efficiency due to the increased costs in the case of olives.

As the general context, chemical pesticides are normally applied to olive trees in controlled, standardized amounts. When substituting organic fertilizers, the eco-efficiency decreases because the greater costs outweigh the environmental benefits. More than changes in cultivation methods, the correct use of organic fertilizers is needed: from transport to application on the soil. Substituting organic fertilizers in olive trees results in a decrease in production, partly because the trees are more vulnerable.

Combined options

A combination of options includes the application of organic fertilizers, sludge from WWT plants and regulated deficit irrigation (RDI); the combination was assessed in two different scenarios. In the ‘super-intensive’ scenario, the organic fertilizers were considered for maize (in both high and low-pressure areas), as the crop with a higher increase in eco-efficiency. RDI was considered for maize, olives and pastures for both low pressure and high pressure areas. Sludge was only considered for pastures (high pressure) due to restrictions on the availability of sludge. The second scenario, the ‘low-intensive’ scenario, applies the combination only in high water-pressure areas, i.e. organic fertilizers applied to maize (high pressure), sludge applied to pastures (high pressure) and regulated deficit irrigation applied to maize (high pressure), olives (high pressure) and pastures (high pressure).

As the comparative results: The super-intensive scenario offers relatively greater improvements for both parts of the eco-efficiency calculation: TVA is increased by 70% in the super-intensive scenario, but only by 36% in the low-intensive scenario. Fossil fuels depletion and eutrophication burdens are lowered much more, the latter mainly by substituting organic fertilisers (D2.4). The comparison is shown in Figure 5.

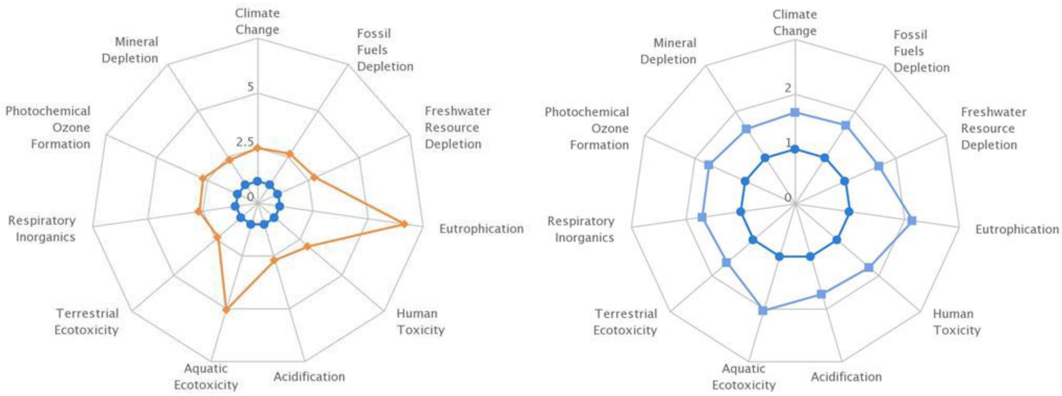

Figure 5 Eco-efficiency comparison for “super-intensive” and “low-intensive” scenarios

Distributional Issues

In the super-intensive scenario above, all actors have increased NEO from the higher TVA, especially farmers. The WUO (ABMN) increases its NEO because its costs fall more than its income.

4.3 Prospects for adopting eco-innovations

4.3.1 Influences on adoption

Organisational responsibilities: In the Alentejo region, more specifically for the Alqueva multipurpose project area, COTR (Centro Operatio e Técnicas de Regadio) has played the role of advisory service for the past years. However, significant cuts in COTR’s budget resulted in a decline of the monitoring and advisory work on the field. The need for advisory services is frequently cited, but no specific path has been determined in order to fulfil that need. The case study highlighted the need to provide an effective, practical connection between agronomic-scientific knowledge and farmers’ perceptions.

PESTLE factors were discussed with stakeholders in the first phase of the project, when defining the case study and the baseline scenario. Considering the adoption of technologies, farmers expressed some interest, especially in organic fertilizers, but the effective adoption of new measures would require more time and work. There is no water shortage in the Monte Novo perimeter, so the main drivers would be lower costs and increased production.

Farmers are reluctant to change how they operate their farms, so this would need a change in mentality. Highly effective innovative technologies are available, but their adoption will depend on a great effort in demonstrating their benefits to farmers. Benchmarking activities and knowledge exchange are essential. Technologies such as RDI are expected to have an increasing role in the region, mainly for grapes and olives.

Changes in public subsidy will be important factors. The water tariff set for 2017 is higher than average in other public irrigation perimeters; and CAP direct payments are tending to decline. The shift to less water-demanding crops can be an option, but there has to be a market for the greater production.

4.3.2 Multi-stakeholder discussions

The study team presented several improvement options at the April 2012 workshop. It was attended by representatives and experts from numerous relevant local bodies, including: EDIA, farmers' representatives (FEA and ODS), the ABMN (WUO), ARH-Alentejo, and the Centro Operativo de Tecnologia do Regadio (COTR).

Stakeholders' comments converged around the following points:

- All the proposed technologies could add value to the Alqueva scheme.
- Farmers are interested in any technological configuration that might increase their profit margins, which are currently low.
- Given the high investment costs of the irrigation scheme, a successful operation is important in order to lower the unit cost of water through access to more growers (D6.1).

Discussion focused on the knowledge lacking for farmers to minimize irrigation intensity and to conserve soil resources. In particular participants made these comments:

- Irrigation intensity must remain within the carrying capacity of the soil (infiltration rate and water-holding capacity), especially in order to prevent surface run-off, leach-outs and erosion – significant environmental impacts that must be taken into consideration.
- Without adequate knowledge for such judgements, farmers may intensify resource usage, thus increasing costs, leach-outs and soil erosion.
- Root-zone soil moisture conditions are not measured to identify in-field variability and vulnerable areas, so most farmers base decisions on their past experience and daily observations of farm conditions.
- Although a network of meteorological stations already exist in the area, relevant information is not available for irrigation planning and scheduling purposes; farmers' access to such information is still under development (D6.1).

The workshop discussion also considered whether the cultivation of organic crops could be an alternative option, along with bio-labelling to gain a higher market price. According to the ODS representative, farmers would use organic cultivation methods if they could be convinced that their profit would increase. But smallholders would not be easily convinced (D6.1). Indeed, small-scale growers lack an advisory service and systematic support for linking organic methods with higher-value markets. This institutional gap illustrates wider difficulties for farmers adjusting to new challenges and gaining the full potential benefits of EFMA's abundant water supply (Levidow et al., 2014).

4.3.3 Policy and institutional implications

Greater incentives are necessary for farmers to adopt the most environmentally-friendly eco-efficient options at the farm level, as identified in the above assessments. The following policy or institutional measures would be helpful (D2.4):

- Simplified licensing for the use of WWT sludge in agriculture.
- Financing mechanisms to ensure access to loans for investment in more eco-efficient techniques.
- Increase of loans' duration with lower rates.
- Better information to farmers about better eco-efficient techniques and agro-meteorological data for better water management on a day-to-day basis, with training through workshops'. This gap could be filled by field-level technical staff, farmers' associations staff and/or public institutions.
- Promotion of biological products in the region/country to increase the demand.
- Assistance to farmers´ associations for easier access to organic fertilizers at a cost lower.

5 CS3 Sofia urban water

5.1 Meso-level system

5.1.1 Eco-innovation context

Sofia's urban water system is sourced mainly from the Iskar reservoir at a higher altitude than the city. Water is transported by pressurized water mains to the water treatment plant (WTP) Bistritsa, situated around 60m lower than the Iskar reservoir. Thus there is a huge potential for hydro-energy at the plant's inlet. The sewage is driven through pressure and gravity. Wastewater is treated at the Sofia WWTP before discharged into the Iskar River.

Sofia's entire water system is managed by Sofiyska Voda (a subsidiary of Veolia) by concession from the municipality, which holds a 22.9% stake. It promotes its reputation as 'an environmentally responsible company'. This involves several aims: to use natural resources efficiently in order to preserve them; to save energy and other resources; and to restrict the continuously growing water consumption (Sofiyska Voda, 2014).

5.1.2 Eco-innovation upgrading

The study explored technologies to upgrade the following aspects:

- Water losses in the distribution network;
- Utilizing the potential hydro-energy in the distribution network and in water mains for electricity production;
- Water consumption in the households;
- Energy consumption of the water appliances in the households;
- Energy consumption for water heating in the households;
- Reducing sludge volume in WWTP to reduce the negative environmental impact due to its transportation

5.1.3 Meso-level boundaries

<u>Directly involved actors</u>: water operator, responsible for water supply and collection and treatment of the generated wastewater; water users, both domestic and industrial; private companies which provide energy and materials to the system.

<u>Indirectly involved actors</u>: state authorities, municipal authorities-agencies and citizens, potentially represented by NGOs.

For Bulgaria's national water policy, major state stakeholders are the Ministry of Environment and Water (setting overall water policy), Ministry of Regional Development (setting policy on urban water supply, and sewerage systems and water operators) and the State Energy and Water Regulatory Commission (regulating water, sewerage and energy services) and the Ministry of Economics and Energy (setting energy policy, relevant to water supply).

Users without centralized sewerage system were excluded from the system boundaries, especially because the study would not consider technologies in the sewerage system. Further distinctions were made among types of domestic water users (D2.2: 10).

5.2 Eco-efficiency assessment

5.2.1 Baseline assessment

The main resource burdens are in the following indicators (D2.2):

- Freshwater resource depletion, due to water losses in the water distribution network and inefficient water use in households (all in foreground);
- Climate change and fossil fuel depletion, due to sludge transportation (all background);

Other environmental categories have significant impacts due mainly to fossil-fuel energy production (all in background, except eutrophication).

As regards those indicators, the baseline assessment identified three environmentally weak stages.

1. Water-use stage, the weakest one for all indicators including aquatic eutrophication. The impact is generated through the transport and processing water to fulfil its service function at the user stage.
2. WWT stage, which shows negative environmental impact in both foreground and background systems.
3. Water-distribution network, which shows the worst performance in regard to freshwater ecosystem impact, the most important indicator of the foreground system.

As above, the greatest resource burdens arise from the householders' water-use stage. Reducing water use there would most reduce energy demand in heating-water as well as for water-dependent electrical appliances, thus also reducing GHG emissions because nearly all the energy comes from fossil fuels.

5.2.2 Technology options comparison

Individual technologies

For technology options, a priority was reducing household water use, which would reduce energy demand for heating-water as well as for water-dependent electrical appliances; this also would reduce GHG emissions because nearly all the energy comes from fossil fuels. The team explored ways to achieve those goals through various domestic water and energy-saving technologies which would maintain the previous water-service value to householders.

As an extra domestic technology for apartment buildings, thermal solar systems reduce the high consumption of conventional energy for water heating by replacing it with a renewable source. This would improve several eco-efficiency indicators, beyond simply fossil fuel depletion and climate change, from energy production in the background.

The water-supply stage could install pressure-reducing turbines (PRT), which offer two benefits: reducing water-leakages in the system, and converting the hydro-potential energy to electricity, thus saving and producing energy from the gravity-fed system. This significantly improves the freshwater resource depletion indicator and somewhat improves other indicators.

As noted by stakeholders at the Sofia workshop (see below), the plant inlet has a huge hydro-energy potential, which could be tapped by installing a hydropower plant there. The generated electricity could be used in the water supply and sewerage system, thus substituting for electricity purchased from the grid. The calculations assumed that the extra energy will be used within the system by the water operator, though hypothetically it could be sold back to the central grid. This offers an improvement in several eco-efficiency indicators.

Combined options

The two most effective options are pressure-reduction turbines and water-saving appliances (as above). As an estimate, total water consumption per capita would be reduced by 10%. The technology combination would offer great resource-efficiency improvements by reducing freshwater resource depletion, fossil fuels depletion and thus climate change (as well as other indicators); the greater eco-efficiency is shown in Figure 6.

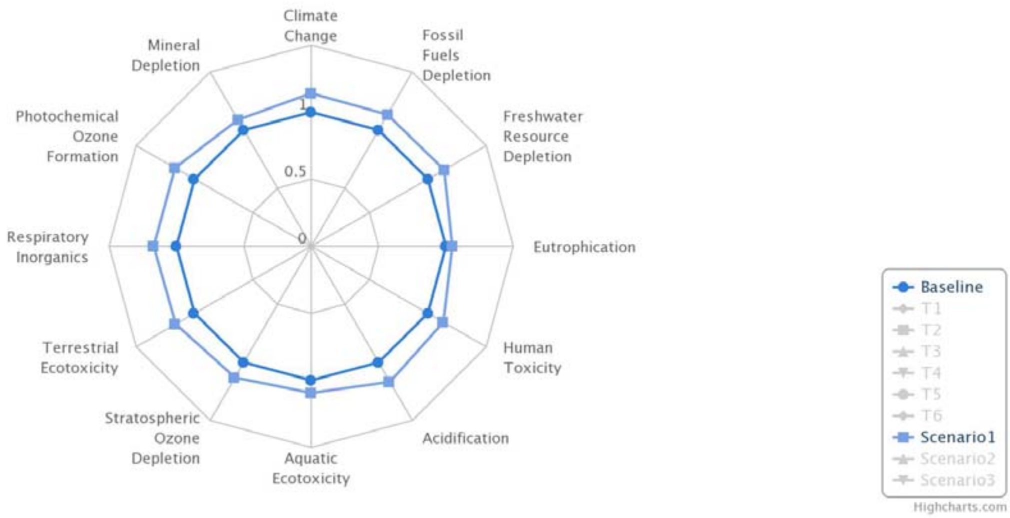

Figure 6 Eco-efficiency performance of combination (domestic appliances + PRT) relative to baseline

Distributional Issues

Each option would redistribute TVA across the value chain in very different ways.

Domestic appliances: To the extent that householders reduce water (and thus energy) demand, they gain the extra TVA, while the water operator would lose NEO under current water prices. Even worse, less water consumption could increase the water pressure and losses in the supply system, thus further lowering income for the operator.

Solar heating panels: Householders would gain the extra TVA by reducing energy costs, while the water operator would have no change.

Hydropower plant: Under current rules, the water operator would gain the extra TVA, especially by replacing and/or selling some fossil-fuel energy. But the rules remain uncertain; see next section.

5.3 Prospects for adopting eco-innovations

5.3.1 Influences on adoption: multi-stakeholder discussions

Organisational responsibilities: Although the water operator has an environmental sustainability policy for its own activities, it had no involvement or responsibility for other parts of the meso-level system.

Held in February 2014, the Sofia multi-stakeholder workshop had 12 participants representing all national and local institutions (except the State Energy and Water Regulatory Commission). The case-study team presented several innovative options (as listed above), aiming to obtain stakeholders' views on: i) those options and any other relevant ones, and ii) the main drivers and barriers of those options (UACEG, 2014; also D6.2?).

To achieve the first aim, stakeholders were asked to prioritise the innovative options for discussion. After the case-study team presented several options (as above), stakeholders proposed three additional options:

1) Extending one of the above technologies, a pressure-reduction turbine, through a small hydropower plant along the pipe feeding the water treatment plant (WTP).
2) Extending another of the above technologies, heat recovery from households, through pumps recovering heat from the sewerage system.
3) Replacing the technology for solar sludge-drying with a technology for sludge incineration.

Participants prioritised the first two of those three options for further discussion, rather than the options originally suggested by the case-study team. Their priorities could be explained by participants' institutional responsibility or stakes in the two options. As another reason why domestic appliances were not given priority, no workshop participants represented citizens or householders.

To identify the drivers and barriers of the above two options, they were discussed in parallel in break-out groups. Group members were selected so that stakeholders from the same institution would join different groups and so that participants would be familiar with the technology or relevant part of the system. Participants individually wrote down their thoughts about drivers (D) and barriers (B) for all PESTLE factors on post-it notes. Afterwards they put their notes in the group's PESTLE table, factor by factor, while discussing each factor within the group.

In general, each participant identified different drivers and barriers, thus bringing extra value to the exercise and confirming its usefulness. For the technology option, 'Energy generation through hydropower plant on the feeding pipe of the WTP', two barriers were mentioned by more than one participant: high initial investment, and unsatisfactory condition or lack of infrastructure.

The discussions also revealed potential stakeholder conflicts over the distribution of costs and benefits. Who would benefit from the extra energy or income – only Sofiyska Voda? or also citizens through lower water tariffs? The stakes of the two main stakeholders – Sofiyska Voda, and Ministry of Economics and Energy – appeared unclear for the option to create a new energy source from the water supply system. If these institutional issues are not clarified, then the improvement potential will be lost, according to participants.

The group dealing with the other technology option, 'Heat recovery from the sewerage system', showed more homogeneous opinions. Participants mentioned three common drivers and three common barriers, as listed here in the standard PESTLE order:

- Political: Reducing taxes for users of 'green' energy is a political driver.
- Economic: Producing energy is an economic driver. High investment for the technology itself and the necessary infrastructure is a serious barrier
- Social: Reducing the service cost is a social driver.
- Technical: Little experience in maintaining such technology is a technical barrier.
- Legal: Absent legislation about planning, exploitation and maintenance is a legal barrier.

The latter barrier was seen as jointly political-legal, i.e. an unclear legal framework for water management and long-term strategies to improve eco-efficiency of urban water systems.

As an omission from the standard PESTLE categories, environmental factors were mentioned by few workshop participants. Renewable-energy benefits would enhance the company's environmental reputation but perhaps are not a strong driver for the necessary investment. Environmental benefits do not straightforwardly become policy drivers in the current context.

Looking beyond the above two options, participants felt that the multi-stakeholder meeting was a good opportunity to exchange information, discuss common problems and share ideas for joint ways forward

5.3.2 Policy and institutional implications

Renewable energy recovery: The Sofia workshop discussed two options for renewable-energy recovery from the water system. For both options, the water operator actor is responsible; it would probably substitute the energy for external sources or perhaps sell some to the energy company's grid. But there is a legally uncertain basis for allocating the economic benefits, which remain a potential conflict between the water and energy companies. According to the multi-stakeholder workshop discussion, a main barrier is 'absent legislation about planning, exploitation and maintenance' of renewable-energy recovery. Statutory clarification would overcome this potential barrier to investment.

Households: No organisation represents householders' interests in domestic improvement options, which would be adopted on an individual basis. This representation gap impedes discussion on ways forward. As a policy option, the water operator could increase the household price or introduce a differential tariff according to volume, thus gaining more income from the users. This would incentivize investment in water-saving technologies. The water operator and water users would jointly invest in technologies aiming at reducing water losses.

6 CS4 Zurich urban water

6.1 Meso-level system

6.1.1 Eco-innovation context and upgrading

Water supply sources in the Canton of Zurich are mainly groundwater and lakes, and partly spring water. Lake Zurich is an important provider of raw water, especially for communities along the lakeside. In the case-study area of Waedenswil, 62% of drinking water comes from the lake. For several decades hydropower sources have supplied electricity for the water system. The WWTP is technologically advanced. The Waedenswil technical system is very efficient on a micro level, by already implementing BAT.

Under Switzerland's new Water Protection Ordinance, around 100 out of its more than 700 WWTPs will have to be upgraded to halve the currently discharged micropollutants. This requirement pushes the authorities to make judgements about resource burdens and health hazards. Techniques such as powdered activated carbon and ozonation have been adopted by some water agencies (e.g. EAWAG, 2009). Many other techniques are still in the research or pilot phase.

Switzerland's new waste directive will require the recycling of phosphorus-rich wastes. Partly in response, in Zurich a decentralised WWT system is being replaced with a more resource-efficient mono-incineration plant. The centralised sludge incinerator is now in place, and a process to recover phosphorus from the ash produced is being tested (Morf, 2013). The recovery technology is still in an evaluation stage; it is planned to store the ash until an economically viable technology can be found.

6.1.2 Meso-level boundaries

The meso-level system encompasses the following stages: freshwater abstraction from surface water bodies or groundwater resources, potable water treatment, water distribution network, water use (domestic and non-domestic users), sewage network and WWT (D3.2).

<u>Directly involved actors</u>: Water operator, responsible for water supply and collection and treatment of the generated wastewater; water users, both domestic and industrial; private companies which provide energy and materials to the system.

<u>Indirectly involved actors</u>: State authorities, municipal authorities-agencies and citizens, potentially represented by NGOs. In particular, the Office for Waste, Water, Energy and Air (AWEL) of Canton Zurich enforces legislation.

6.2 Eco-efficiency assessment

6.2.1 Baseline assessment

<u>Economic Indicators</u>: Urban case studies have a methodological difficulty in specifying the TVA of the water because the product is actually the service provided, so a proxy was found in 'willingness to pay for water services' (as in CS3, D3.2).

Some background processes such as electricity production were considered in the assessment, whereas other background processes such as chemicals production were not considered, partly due to lack of data.

Environmental indicators included micropollutants (as a contributor to human ecotoxicity) because legislation will require their removal in the near future.

According to the baseline assessment, the environmentally weakest stage was domestic water use, which has two main resource burdens.

- Climate change and fossil fuel depletion due to water heating with fossil resources such as gas and oil
- Freshwater resource depletion, due to water use in households.

The foreground system mainly accounts for some environmental impacts, e.g. climate change, freshwater resource depletion, eutrophication, and micropollutants emissions. Climate change is due to the emissions from burning gas and oil for water heating inside the system boundaries; impact much higher than the production of oil and gas occurring outside the system boundaries, partly because hydropower is the main energy source there. The freshwater withdrawal is a purely foreground issue as the water is used abstracted and used inside the system boundaries.

6.2.2 Technology options comparison

The assessment compared several technology options at the domestic water-use level (i.e. greywater reuse, ultra-low-flush toilet, showerhead, solar thermal heating) and at the water operator (i.e. smart pumping, micropollutants removal and phosphorus recovery).

Single options

Greywater reuse

Water reuse systems recycle the greywater from domestic water users. To assess the potential, it was assumed that all water collected from showers and wash basins is used for flushing toilets, while the greywater overflow goes directly to the WWTP. Water reuse systems require more energy and chemical consumption than water-saving appliances. Energy and cost efficiency depend strongly on the type of greywater reuse system and the number of users. More complex greywater systems with several treatment steps cause more carbon emissions than the production of a corresponding amount of drinking water. However, greywater reuse systems offer the potential to save up to 30-40% of primary drinking water and the corresponding amount of wastewater. The assessment assumed that the greywater is treated by a membrane bioreactor (MBR), combining activated sludge treatment for the removal of biodegradable pollutants and a membrane for solid/liquid separation. The economic assessment also had to make assumptions about several variables regarding household investment in the technology.

As the result for environmental burdens, fossil fuels depletion and eutrophication increase slightly, due to greater energy consumption. Some other burdens decline, due mainly to the lower freshwater consumption, with more than 20% decrease in the freshwater resource depletion indicator. Concerning eco-efficiency indicators, there is improvement only in the freshwater resource depletion indicator; while all the others decline.

Smart pumping for the water supply system

The water distribution system in the case study area operates very efficiently; the pumping system has been substantially improved in the last decade. Nevertheless the energy consumption could be decreased by 10% through smart pumping measures. The value added of the municipality would increase by 14% because the operational cost-saving compensates for the investment costs. Given the higher TVA, eco-efficiency increases for several indicators. The Waedenswil water distribution system has already recognised the improvement potential of such measures, so that the efficiency of the water distribution network is being continuously improved.

Micropollutants removal by PAC

Methodologically, the production of activated carbon was assigned to background processes, analogous to electricity production, because emissions occur outside the case study area.

Average concentrations of most typical micropollutants for Switzerland had been measured at the outlet of WWTPs, as basis to calculate the amount of micropollutants emitted per year. Powdered Activated Carbon (PAC) technology can remove more than 80% of micropollutants from WW. Micropollutants pose health hazards which are known qualitatively. But diverse substances vary in their effects, which are difficult to quantify and aggregate, thus complicating a translation into mid-point environmental indicators. The study drew on EDIP97 (Environmental Design of Industrial Products) method as a basis to estimate unknown characterization factors of certain micropollutants. PAC depends operationally on materials which must be regularly renewed, thus increasing sludge production and electricity consumption; these burdens were assigned to the foreground. As the overall change in eco-efficiency, only the micropollutants emissions indicator improves, while other indicators decline.

P- recovery

The Ash-Dec method has a larger literature than alternative methods, so this was selected for assessment. According to the results, the recovery costs are slightly higher than the financial return to the water company. P-recovery may not be implemented for another decade, by when the technique may become economically favourable.

Given the country's already-stringent water standards for phosphorous concentration, extra P-removal does not improve water quality, but it is aimed at reuse. Resource burdens of P-recovery, as well as the environmental benefits of P-reuse, occur outside the Waedenswil water system in a centralised Zurich-wide facility; meso-level indicators do not change.

Combined options

Resource-efficiency would be enhanced by combining two options – greywater reuse and several water saving appliances. All of these reduce the demand on drinking water resources, thus demand on energy and improvement in several eco-efficiency indicators, as shown in Figure 4. Financial losses faced by the water operator and municipality can be passed on to the domestic water users.

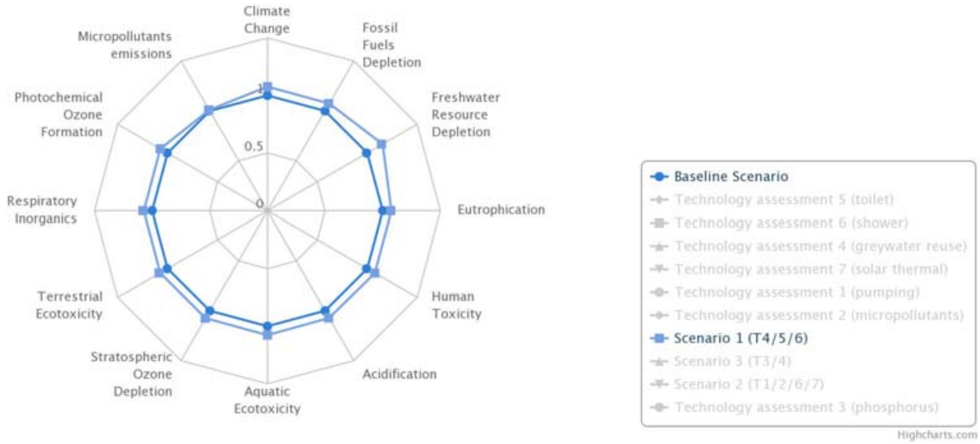

Figure 7 Combining greywater reuse and water saving appliances, compared with baseline eco-efficiency

Distributional Issues

Two options above, relating to statutory requirements, cause the TVA to decline as a loss for the water operator under current conditions. But these may change in the future, partly dependent on political decisions.

Micropollutants removal: In the assessment the technology cost and thus TVA loss was allocated to the WWTP and thus the municipality. On the long term, however, the costs will be passed on to water users through higher WW tariffs because WWTPs must recover costs according to the polluter-pays principle. TVA decreases because there are no short-term economic benefits and no quantifiable long-term economic benefits. The technology may reduce drinking water treatment costs, as the water resources in Waedenswil are taken from the Lake Zurich and already now the micropollutants have to be eliminated at the water treatment stage.

P-recovery: In the assessment the TVA loss is attributed to the water operator, on the basis of current financial information. But the P-recovery plant will not be built for several years, when it may become economically feasible, e.g. if phosphorus prices rise and the recovered P can be sold to farmers. Additionally an intangible value may be attributed to greater independence from imports.

6.3 Prospects for adopting eco-innovations

6.3.1 Multi-stakeholder discussions

Organisational responsibilities: For legislative requirements on water processes and quality, the water operator has full responsibility but may shift costs to other actors.

At the case study workshop held in April 2014, the case-study team presented the overall project concepts, the baseline assessment of the Waedenswil meso-level system and possible technologies for its improvement. Some participants expressed interest in a method for overall system improvement, which would be more useful for politicians than for company managers. According to a participant, the task is to integrate holistic concepts with individual point decisions: how and where would this be done? Under Switzerland's legislation the water value chain is already required to reduce costs and work cost-efficiently, though there is still scope for improvement, e.g. using only renewable energy for electricity to pump the drinking water. Specific options suggested at the workshop were already well known, so attention should be focused on the assessment method and means to optimise decisions (FHNW, 2014).

6.3.2 Policy and institutional implications

The eco-efficiency assessments highlighted trade-offs between different environmental burdens, especially in technological options for fulfilling new legislative requirements. In particular:

Micropollutants-removal entails trade-offs between uncertain health benefits and extra resource burdens, especially from energy production, even apart from economic costs. To clarify these trade-offs and make judgements on them, a policy framework should assess linkages between technology design, its resource burdens, environmental standards and health-hazard reduction.

Phosphorous recovery policy should consider how to combine the current economic loss and environmental impacts from P-recovery, alongside various benefits of its reuse, as a basis to justify technology standards and their costs.

More generally, the value-chain actors aim to increase their own economic efficiency. Therefore, a facilitator and/or additional incentives are needed to introduce measures which are most eco-efficient for the meso-level system.

7 CS5 Biella textile-dyeing process

7.1 Meso-level system

7.1.1 Eco-innovation context

The European textile industry generally imports fabric, carries out wet processes and produces final consumer products. Each stage is generally done by different companies through a chain linking them. The industry has been discussing how to enhance resource efficiency. It has discussed how: (1) to do more with less, (2) to use and re-use resources in multiple cycles and (3) to better measure, monitor and communicate their resource efficiency. Drivers for such improvements include: constantly rising resource-utilisation costs, tightening environmental legislation and emerging market requirements for more sustainable products. Companies need and want to 'close the loop' of their resource usage but face difficulties in adopting such improvements (Euratex, 2012).

The Biella textile-finishing sector exemplifies difficulties of the European textile industry facing higher costs alongside greater competition from cheap Asian imports, produced by highly polluting methods for the environment and fabric content. In the past two decades there has been a significant increase in costs for freshwater, WWT treatment processes and environmental fees. Since 2003 the Biella textile industry (particularly the textile-dyeing companies) has been affected by an economic recession and later the global economic crisis, which reduced sales and squeezed market prices. In 2001 the Piedmonte Region had more than 1400 textile companies processing mostly flock and fibre, though also some fabric and cloth, at various finishing stages; by the year 2012 the number had declined to fewer than 1000 companies. Beyond higher costs, national issues such as the political, administrative and fiscal regulations are blamed for companies' difficulties. Those various pressures have led some companies to suspend operations for process-renovations, to close down altogether or to leave the region. Some have transferred production to cheaper places, e.g. Turkey or Poland (Dansero and Caldera, 2012: 52).

To address the market pressures, environmental issues have been used as a marketing strategy. In the context of the EU's REACH regulations, seeking to phase out the most hazardous chemicals, in 2001 the regional Health Ministry sponsored a new Associazione Tessile e Ambiente [Textiles and Environment Association], with main objective to guarantee the consumer safety and transparency of textile products. This developed an Associazione Tessile & Salute [Textiles and Health Association], certifying safety and traceability (Dansero and Caldera, 2012: 65).

Building on a long-time global reputation for quality wool products, the Biella textile sector also developed a territorial quality brand, 'Biella the art of excellence' since 2003. A generic label informs consumers about the companies' ethical and environmental standards. But the hoped-for commercial success was not fulfilled (Dansero and Caldera, 2012: 43-44).

Biella's products have been promoted as 'Made in Italy'. Instruments include: shared values, corporate social innovation, venture philanthrophy, open innovation. This generic label has helped increase exports to affluent consumers in China, Russia, Brazil and South Africa (Dansero and Caldera, 2012: 34, 47). Some textile companies have been increasing the environmental sustainability of production methods, responding to quality requirements and protecting consumer health, especially regarding allergens in garments. The Biella textile industry seeks new market niches to help resist competitive pressures towards lower cost and quality (Dansero and Caldera, 2012: 3). However, the 'Made in Italy' label conceals the assembly of cheap Asian imported materials which have been produced in environmentally more polluting ways, thus undercutting truly local environment-friendly production.

Despite those efforts, most Biella textile companies have been pessimistic about the future. Some already made efforts at process improvement but see no economic benefit – nor even a commercial future because all costs are too high and local permits are too difficult to obtain. In particular the textile-dyeing companies see freshwater and WWT costs as too high; they resent their dependence on public utilities, especially for WWT (according to EcoWater CS5 interviews). Government policy aims to increase water prices further, partly as a means to lower industry's demand, thus intensifying the economic difficulties.

7.1.2 Dyeing-process: Innovative practices as focus

According to the President of Sistema Moda Italia, the sector's recovery prospects depend on political-economic means for containing production costs, especially energy costs. The sector has high energy demands especially at the washing and dyeing stages at high temperatures (Dansero and Caldera, 2012: 8). Drivers for improvement, as outlined above (Euratex, 2012), can facilitate but also complicate decision-making on new investment, especially in SMEs.

The baseline eco-efficiency assessment (next section) identified the dyeing process as the environmentally weakest stage of the Biella textile industry. Several innovative eco-efficient practices there have been recently developed. To study Biella industry as a 'green economy', academic researchers selected some textile companies 'which are symbolic, though not representative' (Dansero and Caldera, 2012: 48, our translation). These overlap with companies in EcoWater CS5, which focuses on potential improvements in the dyeing process.

Dyeing innovation combines product and process upgrading, while other innovations illustrate the latter.

For the case study, companies were classified as follows:

- Type A: Using standard chemical-dyeing processes, some with in-house WWT.
- Type B: Using natural herbal dyes. In recent decades herbal dyes have been generally replaced by synthetic ones, though some companies have reverted to natural dyes.

In-house WWT is done by approximately 58% of companies which dye cloth, including Tintoria Mancini and Reda (D4.1: 22). According to the Environmental Declaration of Reda (2009), its in-house WWT seeks to address the problem of water scarcity. Since Reda introduced a new process in 2004, harmful pollutants have been reduced by 99.9%, though requiring a 72-hour process rather than the normal 24 hours, eventually recycling 30% of the WW for the dyeing process. Moreover, much of the electric power comes from rooftop photovoltaic cells, thus saving energy (Dansero and Caldera, 2012: 50-51).

Herb-based dyes have been newly developed by the Tintoria di Quaregna. This was a strategic decision pre-dating the greater economic difficulties since 2003. The production cost is much greater – 25 vs 4 euros/kilo of fabric (Dansero and Caldera, 2012: 52) – so this technique depends on a higher final price. Some essential crops are cultivated far from Biella, so the transport is an extra cost.

Although some other companies advertise their herbal dyes as 'natural', only Quaregna directly procures its own herbs and extracts the dyes itself, thus guaranteeing control over the entire production process. Its *Naturale* process is the only one registered with Woolmark. The herbal dyes help staff and consumers to avoid contact with synthetic chemicals, some of which are allergens or suspected carcinogens. Product advertising emphasises health and environmental benefits. According to the company, medical studies have shown that natural dyes have less allergenic activity than synthetics (http://www.tintoriadiquaregna.it; Dansero and Caldera, 2012: 52-53).

Comprising approximately one-fifth of the company's production, the naturally-dyed cloth is sold to garment manufacturers, who in turn supply retailers. The company seeks ways to communicate its brand and benefits more directly to consumers. Quaregna applied to the EC's Eco-Innovation programme for funds to establish a shorter supply chain for its *Naturale* brand, but evaluators criticised the proposal as insufficiently innovative in the production aspects.

Natural-dyeing WW undergoes the same treatment process and costs as WW from synthetic dyes because legislation does not distinguish among types of industrial WW. The similar requirement is not warranted from the viewpoint of the Quaregna (D4.1: 21). Although the wastewater has a high concentration of pigments, it does not contain chemical pollutants; therefore a simple dilution (which already happens in water rinses) may bring the WW contents close to those legally required for return to the river bed, thus reducing the necessary additional treatments.

7.1.3 Meso-level boundaries

After surveying the Biella textile industry, it was decided to focus the case study on the wet-processing stage, especially the dyeing process. For this process, Biella textile industries utilize a large amount of freshwater that is available either as surface or as groundwater, as well as chemicals which may have impacts on the environment and human health. The water and WW processing technologies installed in the region are largely the same as when the industry was established in the previous century, but in some cases they have been upgraded to more efficient technologies, as outlined in the previous section (D4.2: 9).

For the textile-dyeing process, the main actors are:

- Directly involved actors: Biella textile SMEs generally depend on the public agency Corda for WWT, except for some which do in-house WWT (e.g. Reda 2009). Biella dyeing-process SMEs purchase dyes from synthetic or herbal sources, or else they produce their own from herbs, e.g. Quaregna.
- Indirectly involved actors: regulatory authorities monitoring water quality, ATO2 (L'Autorità d'Ambito no. 2), ARPA (Regional Agency for Environmental Protection of Piedmont).

7.2 Eco-efficiency assessment

7.2.1 Baseline assessment

From the baseline eco-efficiency calculations, the most important indicators were: freshwater resource depletion from water used in dyeing processes; and aquatic and terrestrial ecotoxicity, due to chemical dyes and other chemicals used by most companies, except the few using herbal dyes (D4.2: 15).

The two types of company can be distinguished in the baseline assessment. With its in-house WWT facility, Unit A has better performance in climate change, freshwater resource depletion and acidification due to less consumption of electricity and water. By contrast, Unit B has better performance in the two ecotoxicity indicators, mainly because the natural dyeing technique produces cleaner wastewater; regarding human toxicity, however, the background electricity production counterbalances the direct environmental impact from the water effluents of the dyeing process (D4.4). The process has a better performance in all the eco-efficiency indicators, thanks to the 3x greater value of the naturally-dyed wool/kg (Assimacopoulos, 2013a).

7.2.2 Technology options comparison

The Biella case study focused on dyeing as the most water-intensive process in two senses, requiring water and generating emissions in WW. The dyeing process has the greatest potential for technological change to improve water use, especially in response to economic pressures. The study further identified companies and potential changes which represent prospects for improvement in wet processes.

A preliminary eco-efficiency assessment was carried out for six technologies, as presented in Figure 8. Natural dyes and MBR (Membrane Bioreactor) show a large improvement in aquatic and terrestrial ecotoxicity – the greatest resource burdens. Smart pumping systems and LLR (Low-Liquor-Ratio) jet-dyeing systems significantly improve three indicators: climate change, freshwater resource depletion and acidification (D4.4).

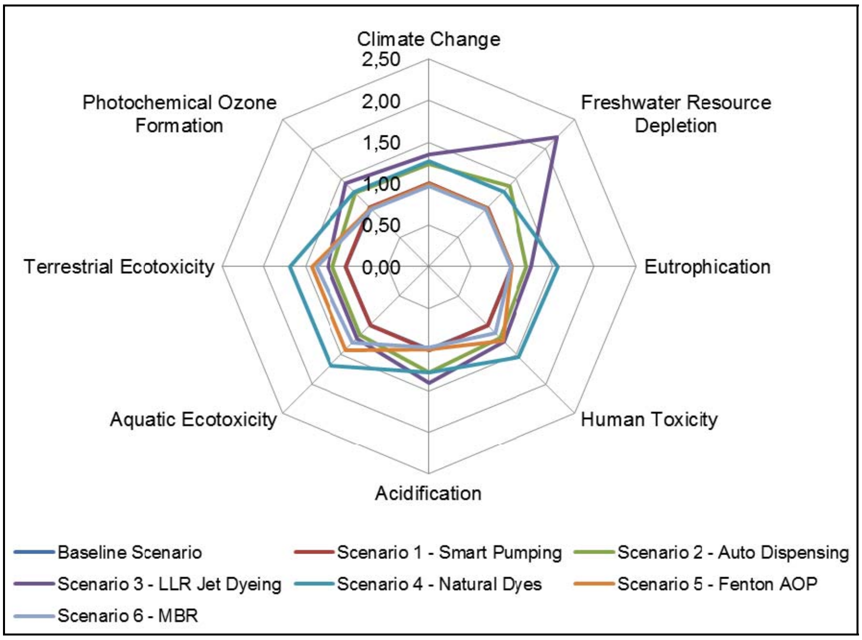

Figure 8 Individual eco-efficiency assessment of the six selected technologies

The greatest resource burdens (aquatic ecotoxicity and human toxicity) would be significantly reduced by three technology options which prevent or reduce pollution – natural dyes, MBR and advanced oxidation process. Moreover, each option improves all eight eco-efficiency indicators and increases the TVA of the entire system. But the NEO of the Industrial Unit A (using standard chemical-dyeing processes) decreases since the economic gain from the new technologies does not counterbalance the high investment cost (D4.4).

Resource efficiency could be increased by three technologies: smart pumping systems, automatic dye and chemical dispensing, and LLR (Low-Liquor-Ratio) jet-dyeing systems. Each improves all 9 eco-efficiency indicators, increases the TVA of the system and either increases or maintains the NEO of all the directly involved actors. But these technologies require a very high investment cost (~€400k) from each industrial unit. Given the economic conditions of the textile industry in Biella, this scenario may not be realistic (D4.4).

Distributional Issues

For pollution-reducing options, comparing the two types of companies, Industrial Unit B (using herbal dyes) gains a much greater TVA than the other actors; the lowest share goes to CORDAR. As noted above, pollution-reducing technologies increase the system-level TVA but lowers the NEO of the Industrial Unit A, given the high investment cost (D4.4).

7.3 Prospects for adopting eco-innovations

7.3.1 Influences on adoption

Organisational responsibilities: Responsibility for economic and environmental aspects are inherently integrated by a management team in each Biella SME. They have a family-based artisanal expertise which has been passed on to the next generation. The few large companies have specialist staff for each technical aspect. Biella province is one of the most famous for top-quality textiles. Probably for this reason the company managers are excessively proud of their capabilities and little open to suggestions coming from 'outside'. Yet some companies identify inadequate technical capacities as a barrier; see 'social factors' in the PESTLE analysis. Although textile companies ostensibly cooperate through their sector-wide organisation (UIB), company members have a fierce rivalry. The participation of industrial managers and policy actors in the study was further impeded by the economic-political crisis. All these factors impede cooperation and eco-innovation.

In textile industry, several barriers have been identified:

- Water-recycling processes are considered as 'not performing' by the industries' long-time company owners.
- Company owners are often rooted in traditional cultures and prejudices, e.g. suspicious of 'outsiders'.
- Actors communicate poorly and rarely share knowledge about best practices or new technologies.
- Actors have fear and distrust towards sharing information or knowledge with competitors.

Biella companies' textile units make several favourable assumptions about the environmental impact of their actions:

- Water withdrawal from wells is correctly done;
- River pollution no longer exists because of regional/national regulations and competent agencies exercising control; and
- Industrial wet-textile processes comply with official rules.

At the same time, companies acknowledge some environmental and organizational problems: excessive use of chemicals; dangers for human health; inadequate attention to water saving; lack of communication and innovation transfer among stakeholders. The largest share of water abstracted for wet-textile processes is untreated, since it is perfectly clear and has a hardness lower than 50 mg/L. These favourable features have led to neglect in specifying the appropriate water quality for dyeing and finishing (Balzarini, 2013 PPt).

In mid-2013 the standard PESTLE table-template (from D1.7) was sent to several companies with a request to list factors influencing their process innovation. The request distinguished between current and longer-term factors, which are combined in the list below. Two companies' responses were combined in a single Table, which includes the following points:

- Political: Excessive bureaucracy; political lacunae in industry access to finance for the best innovations; political-administrative incentives for SMEs.

- Economic: Resumption of sales and trade; excessive tax; access to bank loans.
- Social: Professional training and specialised personnel lacking; industry training (not) officially recognised; problems of relations among different cultures within Italy;
- Technology: Technical means of adjusting to mandatory regulations; fear of tighter regulation for more expensive technologies; institutional support for technology adoption.
- Legal: Simplified, optimised rules, especially for environmental criteria [from Balzarini, 2013 PPt, rather than from the Table].
- Environmental: Current effects on groundwater as the main problem (rather than amount of abstracted water); future water shortages; studies of groundwater to inform companies using private wells; piezometric devices (to measure liquid pressure of groundwater).

7.3.2 Multi-stakeholder discussions

Workshop planning: The EcoWater questionnaire about companies' methods and resource flows was circulated to several companies – initially to obtain essential information for the eco-efficiency analysis, as well as to generate interest in companies' participation in the study. In response, two companies (Quaregna and Reda) sent complete informational responses, and two companies sent incomplete answers. For such small companies, only the Director would be relevant for workshop attendance. By contrast, large companies were less interested in the study. They have complex bureaucratic-administrative procedures; they have specialist researchers to develop internally the best technical solution for the water issues and fear disclosure of confidential information. It was also difficult to attract the WWT company (Cordar), partly because its staff members have changed and seemed reluctant to speak about these issues. Only the above two companies, Quaregna and Reda, attended the workshops.

1st Workshop

At the first workshop, held in November 2013, the EcoWater team presented the project's concepts and methods for meso-level eco-efficiency assessment. After describing the constraints facing the entire local industry, another presentation focused on the wool-dyeing stage, with several options for reducing environmental burdens. Then a presentation applied the EcoWater methods by comparing processes with synthetic dyes and the herbal dyes as used in one company; the latter option had a relatively lower environmental burden (except GHG emissions) and a greater eco-efficiency for every environmental indicator, thanks to the extra market value of naturally-dyed products. The presentation also described three other ways to upgrade the textile-dyeing value chain for greater eco-efficiency (Assimacopoulos, 2013a). Tintoria di Quaregna presented its innovation in herb-based dyes replacing chemical-synthesis agents and its attempt to reduce intermediaries the retail chain (see above for detail).

The Politecnico Torino-Biella presented its research programme on ‘Water recycling for wet textile production’. This tests parameters of production inputs and conditions, with the aim to save energy costs and reduce emissions (Rovero and Grande, 2013). Companies co-fund the Politecnico for several pilot plants at their industrial sites, where the Politecnico researches various methods of WW treatment, especially as a basis to facilitate water recycling. The research investigates two different scenarios for platforms which could commercialise such innovations: either the WWT company Cordar, or a consortium based in one textile-dying company (Filidea) where the Politecnico has a research unit.

Cittadellarte-Biella runs a campaign *Tessile & Salute* [Textiles & Health] publicising the health hazards of toxins in garments, as grounds to develop and purchase safer alternatives (see above). This campaign has been precarious: after losing its government grant, it nearly closed down but was saved by company funding. By testing garments imported from Asia, it found that 80% contained hazardous chemicals, also indicating dangers to workers in the production process. But few retailers are interested in such issues – by contrast to the great interest in food production avoiding synthetic chemicals.

<u>Discussion points</u>

If Biella companies recycle their wastewater, then this innovation could be beneficial but would not save their businesses from the competitive pressures, partly because recouping the investment would require a long timescale and protection from declining prices. There is no regulation protecting European textile production as high quality excellence, nor any product traceability for the “Made in Italy” label, whose product components may be imported from Asia. Biella companies need to gain attention globally for their environmentally better techniques; the consumer interest in fashion must be extended to environmental criteria and consumer health. As an important message: a healthy body needs to take care of our skin as a major organ. Such an eco-innovative shift in production and markets away from hazardous chemicals needs support from political leadership.

For the option to install in-house WWT, the discussion identified potential difficulties for textile companies and likewise for the WWT company (Cordar), which thereby would have fewer clients paying fees to cover its costs. The EcoWater team proposed a next step: to facilitate a discussion – between Cordar, the environmental protection agency and textile companies – about potential changes in the WWT process. Such a discussion could clarify options and a cooperative basis for decisions. This proposal was welcomed by representatives of the two textile companies in attendance, but it was not taken up by Cordar.

2nd workshop

Following a couple meetings between MITA and UIB (Industrial Union of Biella), it agreed to organise a workshop for its textile-dyeing members. But after several months there was no sign that UIB would do so. So MITA went ahead, inviting the two companies which had contributed to the project with their workshop attendance, data and dialogue. At the November 2014 workshop the two companies’ comments included the following, elaborating on points from the 1st workshop:

Tintoria Mancini: Our dyeing tanks should be replaced for greater eco-efficiency, but we are unable to change them because new tank costs as much as one year's company profits. As sales decline, we barely break even. It would be a disaster to create a bank debt without being certain of repaying it. The banks will not loan funds for new technological investment, so the financing is our problem. Local institutions do not help because they lack funds; even if they had funds, the procedures are so long that the technologies are already obsolete by the time of use.

For the textile-dyeing industry a big problem is the coming scarcity of some chemical component resources, inducing higher prices and thus the need to find new systems. Otherwise in the future we will probably go back to natural-herbal dyes.

Tintoria Quaregna: Our naturally-dyed product requires great efforts to maintain its long-distance, higher-priced specialty market. Many competitors send their fabrics to be dyed in places where costs are lower, i.e. in countries which exploit cheap labour and where chemicals are little or not controlled, but the end-products bear the label "Made in Italy", thus deceiving the consumer about commercial quality and safety.

7.3.3 Policy implications

Technology options which would most increase eco-efficiency, especially for the greatest resource burdens, remain economically unfeasible. They have a very high investment cost, with uncertainty about obtaining and/or repaying the necessary loans, especially given the worsening prospects for sales. Thus implementation would depend on economic incentives such as environmental taxes or subsidies (D4.4).

For product upgrading such as herbal dyes, another obstacle is the difficulty to create or expand long-distance specialty markets. EC policies seek opportunities for new 'green' markets (CEC, 2008: 16), especially through environmental and social labelling of clothes supported by value-chain traceability systems (EEA, 2014: 120). Quaregna applied to the EC's Eco-Innovation programme for a grant to shorten the supply chain for its *Naturale* brand, evaluators expressed a narrow view of innovation as capital-intensive technology. Evaluation should also consider value-chain innovation for 'green' markets.

8 CS6 Energy cogeneration

8.1 Meso-level system

8.1.1 Eco-innovation context

Energy cogeneration, also known as CHP (Combined Heat & Power), has higher energy efficiency than separate production of each component. CHP plants have been established mainly in markets with large heat demand, especially in energy-intensive industries, greenhouse horticulture, services in large buildings and residential areas. But the latter depends on a large-scale, long-term expensive investment in district heating systems. Combined-cycle gas turbines have been the main energy source for industrial applications and district heating systems, so non-fossil fuel sources would be an improvement. This case study explored improvement for a specific cogeneration plant in the Netherlands (see next section).

Among EU member states, the Netherlands has made relatively greater efforts to expand CHP, with the greatest success in industrial use. State programmes also sought to expand domestic use in the 1970s-80s, but few district-heating plants or systems were built. They faced at least four barriers, especially arising from different drivers of electricity and heating (Schaeffer & Struker, 1994; cited in Raven & Verbong, 2007: 497):

i. Local gas distribution companies were often owned by municipalities, separate from regional electricity companies owned by provinces. Most district heating organizations were established by electricity companies, which thereby were competing with natural gas, provoking opposition from municipal gas companies.

ii. Dutch consumers preferred individual heating systems for their reliability. By replacing gas, district heating system forced users to cook with electricity – which they resisted and linked with a general aversion to collective services.

iii. The tariff structure for heat supply was matched with natural gas tariffs – a low fixed amount (standing charge) and a large variable one, according to specific users. But this structure did not reflect the cost structure of heat supply, with its high capital costs and low energy-operation costs, thus resulting in financial problems.

iv. Heat demand was lower than expected, reduced by several factors – a successful national programme for house insulation, smaller new houses and delays in house-building programmes.

All these factors have limited the development of CHP. “District heating (in particular developed by electricity distribution companies) failed to become a success due to opposition from gas distribution companies and a lack of integration in the heat-user context” (Raven & Verbong, 2007: 501). Facing great financial losses by the late 1980s, district heating companies were ultimately saved from bankruptcy by Dutch government aid.

From the mid-1990s onwards, new district heating plants were built only on Vinex sites, a government scheme to expand house-building. Under the Vinex policy, the Utrecht area was chosen as the location of the largest urban extension (Energie-Cités, 1999). Some energy improvements were funded, including heat and cold storage (Project MEELS, 2003). But efforts towards district heating were complicated by government policy to liberalise the energy sector, thus further fragmenting responsibility.

The EC Cogeneration Directive (EC, 2004) mandated greater district heating, but this had little expansion in most member states including the Netherlands. As an exception, Denmark's 1979 Heat Supply Act mandated development of district heating systems, as an essential conduit for using large quantities of surplus heat (Østergaard, 2010). The EC's earlier commitment was elaborated by the 2012 Energy Efficiency Directive (EC, 2012). More recently, Amsterdam municipality has made a commitment to increase district heating (Gemeente Amsterdam, 2013), though specific support measures remain unclear.

Cogeneration involves wider strategic issues. Energy production is caught between pressures of lower electricity prices and imperatives to reduce GHG emissions, especially to comply with EU targets. According to the main cogeneration company in the Netherlands, recently it became even clearer that the traditional business model, based on large-scale electricity generation in conventional power plants, is being challenge. Costs must be lowered along the entire value chain, the production portfolio must be restructured and flexibility must be increased where technically possible (NUON, 2013: 4, 6).

In particular the company plans to expand heat supply to district heating, alongside heat-storage facilities to provide peak-shaving amidst intermittent demand. Expanding further in district heating projects also provides valuable opportunities to expand further in renewable energy, as district heating provides a significant reduction of CO_2 emissions in comparison with conventional gas-heated boilers. District heating fits well with Nuon's strategy, since it offers a 50% to 80% reduction of CO2 emissions compared to conventional gas-heated boilers, depending on the source of the heat (NUON, 2013: 7, 11).

8.1.2 Innovative options as focus

The case-study CHP plants deliver electricity to the Dutch electricity grid and thermal energy ("heat") to Amsterdam's thermal energy network. The facility has sought ways of adjusting heat supply to demand as regards timing, quantity and temperature. Since 2006 the facility has included heat-only boilers; these are used during times of high demand for heat and/or low wholesale prices for electricity.

A thermal storage facility was being constructed in 2014 (during the final year of the EcoWater project and after the 1st workshop). Such a facility is used for peak shaving, i.e. delivering heat during periods when peak thermal energy demand can most efficiently be met by using stored thermal energy. This reduces the generation capacity necessary to fulfil peak demand.

Maximising useable heat

An environmentally weak aspect is the waste or residual heat lacking a use and potentially causing thermal pollution to the local river. There are two key factors in useable heat – its temperature and use time. Industrial-use heat requires very high temperatures. District heating typically uses distribution temperatures of about 100-120°C.

Each cogeneration plant is designed for a specific power-to-heat ratio, which has flexibility in the operating temperature. Maximizing power production requires the lowest possible temperature at the condensing site of the generator, but this in turn depends on greater water-tapping (cooling), thus generating more excess heat. A higher condensing temperature yields higher-temperature heat, which has a higher economic value, especially from more flexible potential uses (Verbruggen et al., 2013: 578).

From a micro-level perspective, e.g. an energy plant per se, the priority is to maximise power generation as the most lucrative product. From a meso-level (whole-system) perspective, by contrast, priorities are to maximise usable energy and consequent income while minimising resource burdens, especially high-temperature wastewater. So optimal operation depends on a slightly higher temperature of heat export. 'Preliminary calculations show that there is a serious business case in this total system approach' (D4.3).

For the above reasons, a higher temperature offers savings in three indicators – cooling water, CO_2 emissions and energy demand. But this option has disadvantages, since investment in different equipment would be necessary to tap electricity at a higher temperature, as well as to transmit the hotter heat. These difficulties compound the lower income through less electricity generation.

Another key factor in useable heat is the use time, i.e. the time-period when thermal energy is consumed. Use time is important for the application to domestic heat supply, where demand varies over the day and with the seasons. In practice heat peak demand for domestic heat occurs only a few days per year, and heat demand for house warming exists only during 30-50% of the year. During the rest of the year (the non-profitable time window) most of the produced heat remains waste heat to be discharged in cooling water. Given this constraint, eco-efficiency depends on the heat transportation and distribution network.

In the Netherlands context, heat demand is much larger than production in power plants, as shown in the comparisons below:

- Power plant production power: heat ≈ 1:1
- Domestic demand power: heat ≈ 1:5
- Industrial demand power: heat ≈ 1:10
- Heat demand domestic: industry ≈ 1:3,5

Domestic heat demand lasts for 4-5 months a year, useable at a relatively low temperature. Industry's heat demand lasts for 11-12 months a year, requiring a relatively high temperature. So greater efficiency needs a combination, perhaps in a cascade from high-temperature industrial use to lower-temperature domestic use. A difficult constraint remains the maximum heat tariffs, based on gas-only delivery, as in the 1980s (D4.3).

The case study focused on ways of adjusting heat supply to demand (as regards timing, quantity and temperature), better using excess heat and reducing heat burdens on cooling-water sources. The overall objectives were originally formulated as follows:

1. Finding the most effective ways to improve the water quality of the receiving body, by reducing (the impact of) thermal discharges.
2. Finding the most effective ways to improve sustainability in the energy sector by better accommodating electrical and thermal demands, leading to reduction of fossil fuel based heating.
3. Finding the best sustainable ways to improve the robustness of the energy sector, by reducing the dependence on the availability of cooling water (D4.1: 27).

To pursue those objectives, the study initially explored five potential options (D4.1: 39-40). After further investigation, the list was adjusted (see next section)

8.1.3 Meso-level boundaries

For the cogeneration plant, the meso-level system encompasses four main stages (D4.1: 28-29):

- River water system, which provides supply and discharge of cooling water used by local energy plants for electricity and thermal energy production
- Local energy plant
- Storage and distribution network,
- Houses and industries where the energy is used.

This case study also anticipated eco-innovations such as supplying pre-heated water or district heating to households, thus reducing their demand for natural gas. So the backgroud system encompassed the supply of natural gas and its resource burdens (D4.4).

In the above company-wide context, the EcoWater study initially focused on one plant, but it was reluctant to cooperate and had conflicts with other stakeholders. So the focus was switched to another cogeneration plant, which supplies the main grid for electricity transmission. It also supplies heat to the district heating system of the city of Amsterdam (Zuid-Oost and Ijburg) and the city of Almere. Relevant actors are as follows (D4.1: 37 and D4.4):

- Directly involved actors: water supply (Rijkswaterstaat or RWS), energy production company, energy storage, energy users, gas supplier and grid operator. The latter category could be expanded via extra uses of residual heat and the natural gas supplier.
- Indirectly involved actors: water and regulatory agencies; municipalities, housing organisations, water boards.

District heating systems had been installed in a newly built neighbourhoods in the Netherlands (and elsewhere), but there was little residential building activity near the plant. So more district heating would replace and/or jeopardise previous investment in heating systems.

8.2 Eco-efficiency assessments

8.2.1 Baseline assessment

For simplicity, the baseline assessment initially presumed no heat transport to customers. It is assumed that the CHP plant maximizes its electricity production and the generated heat is discharged with the cooling water. The customers of electricity satisfy their heat demand by in-house boilers and they are not connected to a district heating system (D2.2: 20).

Total Value Added is mainly determined by two terms – the price of natural gas and the price consumers pay for energy; both prices depend on market developments and governmental regulations.

Main environmental burdens are natural gas consumption which generates CO_2 emissions and toxic emissions to air; and large amounts of waste heat from cooling water sent to the local river. For the latter, ‘thermal pollution’ was added as an extra environmental impact category. All these burdens lie in the foreground of the system (D2.2: 23-26).

Potential improvements could increase income and reduce fossil-fuel demand by consumers. The most obvious way to increase the eco-efficiency is by utilizing the waste heat which is discharged with the cooling water. Using the heat, the amount of gas burned in backup boilers and domestic installations to provide thermal energy will be significantly reduced. This will also contribute at an improved economic performance, by increasing the Total Added Value, and decreasing the amount of CO_2 exhausted from backup boilers, lowering the environmental impacts (D2.2: 28).

Later in the study, a broader meso-level baseline included the following: heat-only boilers (installed since 2006), thermal energy buffers (being installed in 2014) and households already connected to both district heating and the natural gas system. This broader baseline allowed comparisons with different potential improvements (D2.4).

8.2.2 Technology options comparison

The eco-efficiency assessments focused on options for adjusting heat supply to demand, better using excess heat and reducing heat burdens on cooling-water sources. The former options would reduce the use fossil fuels in the entire system. All these options would increase resource efficiency.

To identify the benefits of actual improvements, their absence was compared with the baseline situation. Ommitting the heat only boilers and the buffer, results in significant import of electricity from the background. As the environmental footprint of this background energy is worse than of the foreground system, the BAU performs for background related environmental pressures much worse than in the scenario BAU minus boilers minus buffer (Figure 9; D4.4).

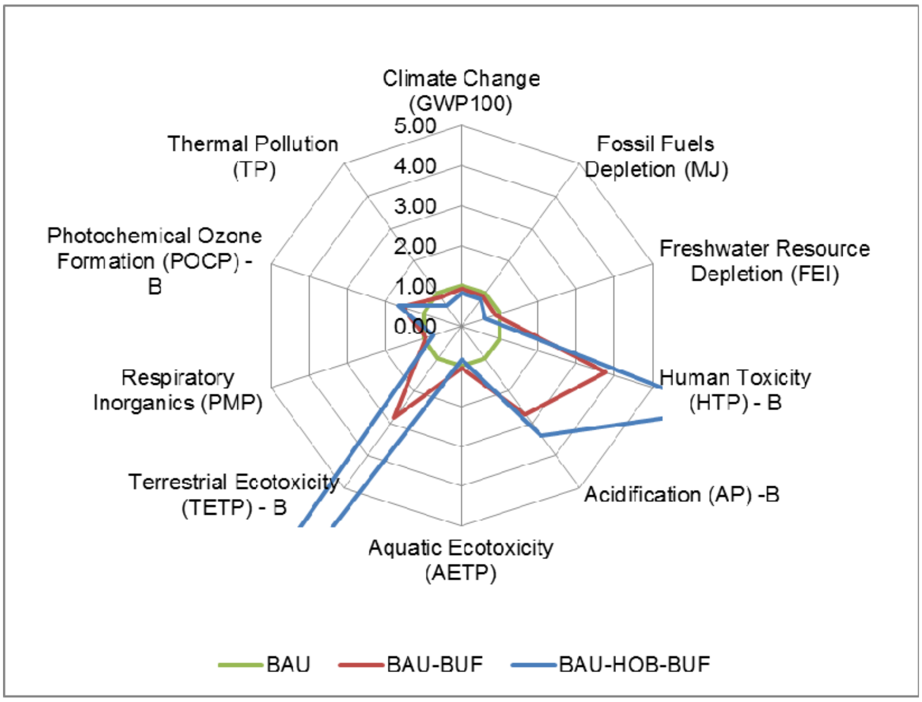

Figure 9: Eco-efficiency comparison of BAU and without the thermal energy buffer, and without former and the heat-only buffer.

The baseline (including BUF+HOB as above) was compared to two potential changes in heat-water supply. Pre-heating potable water would offer significant benefits: the company could supply 10-degree warmer water, thus reducing natural-gas usage for hot water. This would increase TVA, while improving indicators especially for thermal pollution and acquatic toxicity (Figure 10; D4.4).

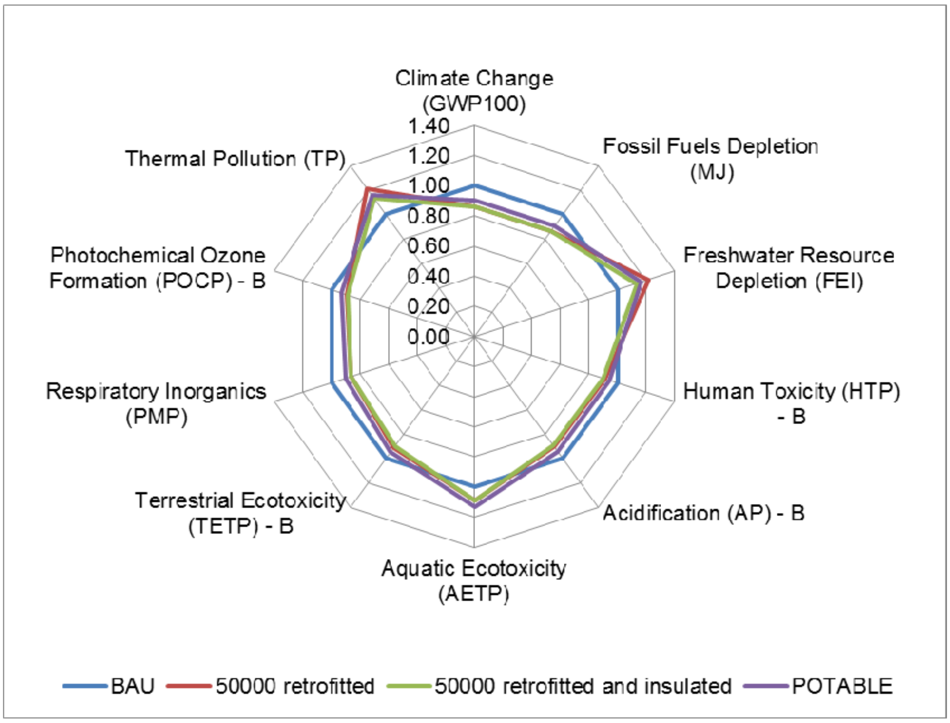

Figure 10 Eco-efficiency comparison of BAU with retrofitting more homes and with potable water preheating

As another option, retrofitting more homes to the district-heat grid would offer even greater improvements on all indicators. Those two options would change the economic balance among actors: homes would have lower natural gas use, the water company would have greater investment costs, but the gas retailer would lose income.

Distributional Issues

Heat buffers make less difference than heat-only boilers; both were assessed via their absence from the baseline situation. Heat buffers increase TVA and the energy producer's NEO. Heat-only boilers likewise increase TVA, while shifting NEO from the heat wholesaler to the heat producer (D4.4).

Pre-heating potable water would increase TVA, while slightly changing its distribution. Consumers would require less thermal energy; current thermal energy users and traditional consumers would gain NEO. Energy producers and wholesalers would lose money, while energy retailer would have increased NEO (D4.4).

For technologies that increase eco-efficiency, environmental indicators would improve much more than the TVA. But for some options (especially district heating) it was difficult to model the operational costs. While annual data on water and energy were reasonably well available, most economic data had to be estimated. There is complexity of energy and heat usage, which vary throughout the year; for this case study the EcoWater toolbox was extended to include time-variability. Economic data were difficult to obtain. Prices paid by consumers and wholesale prices were available, but it was unclear at what prices electricity production become uneconomic. Most importantly new technologies require significant investments whose costs are case-dependent. So it is difficult to estimate cost-changes of technology options, much less to anticipate redistribution of TVA across the value chain.

8.3 Prospects for adopting eco-innovations

8.3.1 Influences on adoption: w*orkshop discussion*

Stakeholders around cogeneration plants rarely discuss the meso-level issues under study here, especially district heating. Such discussion would involve a transition in roles from stakeholder to shareholder, towards generating a Combined Business Model across the value chain (Bruggers, 2013). The case-study team discussed the above issues with stakeholders, who thereby became interested to participate in the study, especially the workshop.

The workshop was held in November 2013 – after the study identified useable heat as a key aim for resource efficiency, but before evaluating specific options (as above). It was attended by representatives of numerous stakeholders. After presenting the overall EcoWater project, the organisers explained the case study, especially potential relations between the energy/heat ratio, operational temperature, usable heat and resource savings.

The workshop discussed the necessary conditions for establishing a thermal network in the local context. District heating systems had been installed in a newly built neighbourhoods in the Netherlands (and elsewhere), but there was little residential building activity near the plant. So this solution would replace and/or jeopardise previous investment in heating systems.

For a local heat network, the workshop also discussed drivers and barriers, whose interactions were depicted in an influence diagram (Figure 11). Some key points from the discussion: The company's commitment to extend district heating would need political confidence in future favourable conditions, especially through 'consistent governance for a 30-50 year period'. Amongst such conditions for such investment: a thermal network needs a price equal to gas-based heat; and CO_2 emission credits need to be made more expensive, so that low-carbon energy becomes more competitive (Goossens & Meijer, 2014).

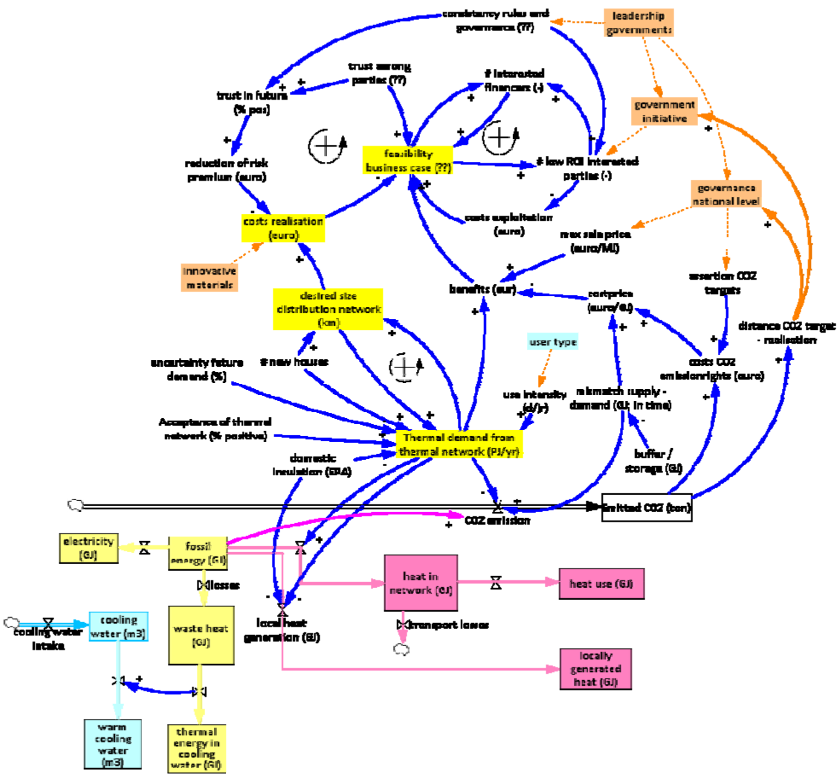

Figure 11 Influence diagram for establishing a thermal network (Arrows indicate inter-related influences: positive sign = driver, negative sign = barrier)

Stakeholders face a circular dilemma: If there is no heat network, then there will be no demand for district heating; but without demand, there will not be investment in a heat network. The workshop discussed two visions for a transition:

(1) A thermal network is a private initiative: private-sector parties finance and realise a network, and then provide exploitation and maintenance. Here governments can promote the transition only through legislation, governance and facilitation.

(2) A thermal network is a public-service utility like the electricity or roads, connecting various sources and many users. Here the government has a strong role in organizing the network, providing opportunities to its users, and exploiting and maintaining it (Goossens & Meijer, 2014).

These two scenarios provided a basis for multi-stakeholder discussion on possible ways forward.

In the months after the workshop, some prospects became clearer. Under foreseeable circumstances, the company will not make a priority of reducing the electricity-heat ratio to yield higher-temperature heat, nor of linking the plant with a district-heating system. More modest options have been pursued. Year-round demand for heat would help, especially from industrial users, so these have been sought; but the company has found no clients interested to buy higher-temperature water for heating. Peak-shaving of daily peaks (via a heat buffer or storage facility) would reduce the temporal mis-match between demand and supply of electricity. This modest investment offers a relatively modest improvement in resource efficiency and GHG savings, while also significantly lowering costs. When it becomes operational at the Diemen 33 plant, the peak-shaving facility will reduce use of the CCCT or heat-only boilers during the daily peak-demand for heat.

8.3.2 Policy implications

Resource-efficient cogeneration, also known as combined heat and power (CHP), depends on using the waste heat through district heating. Since the 1990s the EU has had a policy to promote district heating, as formalised in Directive (EC, 2004), but this has been little implemented. As a major exception, Denmark has had strong support from civil society organisations successfully promoting district heating. When planning a subsequent directive on energy efficiency, the European Commission acknowledged that the Cogeneration Directive 'failed to fully tap the energy-saving potential' of CHP (CEC, 2011), but hardly analysed why.

The 2012 EC Energy Efficiency Directive elaborated the 2004 commitment:

> *High-efficiency cogeneration and district heating and cooling has significant potential for saving primary energy, which is largely untapped in the Union. Member States should carry out a comprehensive assessment of the potential for high-efficiency cogeneration and district heating and cooling. These assessments should be updated, at the request of the Commission, to provide investors with information concerning national development plans and contribute to a stable and supportive investment environment….*
>
> *New electricity generation installations and existing installations which are substantially refurbished or whose permit or licence is updated should, subject to a cost-benefit analysis showing a cost-benefit surplus, be equipped with high-efficiency cogeneration units to recover waste heat stemming from the production of electricity. This waste heat could then be transported where it is needed through district heating networks (EC, 2012: 6).*

The EcoWater cogeneration case study reveals tensions between resource efficiency at the micro-level (company) and meso-level (whole-system). From the latter perspective, resource-efficiency would be greatly improved by a thermal network using all the waste heat, but this would depend on expensive long-term investment and elusive heat-users, as well as less income from electricity production. Informed by a whole-system analysis, a multi-stakeholder workshop highlighted those tensions and identified areas for policy attention.

As discussed at the case-study workshop, the energy company's commitment to district heating would need political confidence in future favourable conditions, especially through 'consistent governance for a 30-50 year period', as well as district-heating price comparable to gas-based heating. Such conditions seem elusive. This case highlights the need for extra support, perhaps through a public-service utility, in order to implement the EC's policy on district heating (EC, 2004, 2012).

9 CS7 Arla Foods

9.1 Meso-level system

9.1.1 Eco-innovation context

Dairies have many opportunities for eco-innovation 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.

Integrated Pollution Prevention and Control (EC, 1996) has helped to stimulate some improvements. This gives priority to prevention of pollutants instead of their treatment, thus supporting measures that constitute the basis for eco-efficiency improvements. This could be done through permits for specific technologies and/or emissions. Permits set no limit on use of energy and water (Honkasalo, 2005). In many member states such as Denmark, environmental licences set limits on water use and discharge.

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. Opportunities arise at several stages, e.g. reducing the generation of separator sludge, while optimising its collection and disposal; improving energy efficiency of refrigeration systems; optimising cleaning-in-place (CIP) processes for filtration units to reduce both water use and the organic load discharged into the effluent stream. Solid discharges from the centrifugal separator are collected for proper disposal and not discharged to the sewer: 'Cleaner Production opportunities specific to this area are related to reducing the generation of separator sludge and optimising its collection and disposal', according to a Danish report (COWI, 2000). A JRC report discusses improvement options in animal husbandry, mainly regarding animal feed, ammonia emissions and nitrogen leaching; but it does not mention milk processing or water in particular (Weidema et al., 2008).

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).

Arla Foods

Arla Foods have been going beyond the innovative practices of the European dairy industry, especially by adopting or considering major changes in the water-use process. Environmental aims encompass the farm and processing stages. 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 reduce energy and water use in production processes by 3% every year (Arla, 2011). It espouses a 'holistic approach to the production chain from cow to consumer' – an elaboration of 'farm to fork' (http://www.arla.com/closer-to-nature/environment/).

The company strategy has sought a competitive advantage among consumers, in ways going beyond any regulatory standards. Arla has made great investment in IT systems for greater quality control over the process and product (Novotek, 2007).

Arla Foods owns approximately 40% of dairies in Denmark and many abroad, especially resulting from an expansion policy (Arla Foods, 2013: 2). Accountable to the farmer-owners who supply the milk, Arla management seeks 'to help them obtain the highest possible price', linked with efficiency improvements. Arla is currently producing significant growth in turnover, but it is the management's assessment that Arla must decrease its annual costs by 500 million DKK in order to keep up with international competitors. Consequently, Arla will be organised in a more efficient way, to ensure a competitive milk price to cooperative owners and to prepare the organisation for further growth.

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 specialty 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.

Relative to the dairy industry, Arla Foods has gone further in eco-efficiency improvements. Arla plants have already adopted resource-efficiency measures, e.g. cleaning-in-place systems to minimise water use and effluent. Water extracted from milk is reused in rinsing casein protein (D 1.7). Most improvements depend on changes in internal production methods, especially for reducing inputs and waste or reusing the latter, e.g. for biogas production. Some improvements depend on re-using waste outside Arla Foods' operations (Arla, 2011).

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. Arla Foods also expanded use of renewable energy sources, since the milk powder plant in Visby now receives about 40% of its energy as biogas, which is purchased from a unit that generates biogas mainly from manure from farms (Arla, 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. Eco-innovation seeks a 'natural' milk-protein ingredient through a new casein process avoiding use of acid hydroxides (Hansesgaard, 2013).

Such innovations have been driven by several factors – the company's environmental strategy, the 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 decisions on innovation investment (Nørgaard, 2013). Owned by farmers and accountable to their representatives, Arla also aims to counter the recent trend towards lower farm-gate milk prices (Arla, 2013: 3).

9.1.2 Eco-innovation upgrading

Impetus for eco-innovation has come from the company's ambitious expansion plans, its interest to protect farm-gate milk prices, and its environmental targets aimed at consumers. 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.

The dairy sector has two water sources – groundwater and milk – which contain 89% water. The Arla case study initially surveyed innovative practices which could (i) switch the source from groundwater supply to surplus water from milk processing, e.g. through advanced membrane technologies, and (ii) reduce emissions of treated wastewater to the end recipient, e.g. freshwater streams or the sea (D4.1: 41). After investigating numerous technology options (D4.1: 47), the study looked at differences between two dairy plants:

- Rødkærsbro Dairy produces cheese. It has its own WWTP (pretreatment, primary and secondary), while turning sludge into biogas. It pays a low rate to the municipality for WWT.
- HOCO Dairy at Holstebro produces protein-specific milk powders and so must remove more water than Rødkærsbro Dairy. It pays a high fee to a WWTP, Vestforsyning, whose sludge goes free-of-charge to a local biogas plant (D4.1: 46). IT systems control the conditions and flows at every process stage.

The EcoWater case study focused on Arla's Holstebro HOCO plant, which was paying the municipal WWT company.

9.1.3 Meso-level boundaries

Directly involved actors were initially identified as: HOCO milk powder producing dairy, Vestforsyning A/S water supply utility, Vestforsyning A/S wastewater utility, biogas plant (Maarbjerg biorefinery) (D4.1: 45-460). Later it was decided to include the private companies transporting raw materials and waste products by lorry because significant amounts of water are bound in these material streams. The inclusion of these processes led to the addition of new environmental impact indicators (D4.2: 29).

The list of directly involved actors originally included farmers and consumers, but neither actor-category is relevant to potential future changes, which would not affect the milk input or the consumer product. Arla plants generally pay external agencies for WWT, which uses anaerobic digestion to process sludge into biogas. From the AD process the mineral-rich digestate is offered to local farmers on a non-commercial basis. So this resource reuse does not count in the value chain.

Indirectly involved actors are the water and environmental-regulatory agencies. The Environmental Protection Agency deals only with statutory requirements such as restrictions on effluents. Arla's eco-innovations and wider environmental aims go further. The Danish Nature Agency plays an advisory role on environmental issues going beyond statutory requirements.

9.2 Eco-efficiency assessment

9.2.1 Baseline assessment

Sufficient data were available from annual reports from the relevant companies and from additional data collection to map resource flows and monetary flows. For HOCO Arla dairy it was necessary to collect additional data on internal water streams to enable a split-up of the dairy process into separate unit operations. HOCO receives its water and discharges its waste water to municipal plants, so the assessment included only data from the proportion which relates to the production in the dairy plant (D4.2).

As the results showed, the environmentally weakest stage is the milk processing, where main environmental burdens are eutrophication and acidification – both due to background processes, mainly the water supply. The next most important burdens is climate change; approx. half comes from the foreground system, while the other half is due to energy use for process heating and circulation pumps. Freshwater resource depletion is moderate, coming from the foreground system. Therefore technological solutions should be examined in order to reduce consumption of water and fossil fuel (D4.2: 36-38). The wastewater treatment plant reduces environmental impacts to a low level, so this stage was not a focus for eco-innovation but potential changes there were important for the assessment.

9.2.2 Technology options comparison

The HOCO 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.

Somewhat different than the above list, five technology options were selected for comparison with the baseline, aiming especially to improve eco-efficiency for the climate change and freshwater resource depletion indicators. The greatest improvements in those indicators would come from three options:

- Anaerobic pre-treatment;
- Advanced oxidation and UV light treatment; and

- Reuse of condensate from product-drying.

The latter two options re-use internal water. Those options would increase resource efficiency and/or reduce pollution.

The eco-efficiency increases were due mainly to lower resource burdens because the economic improvement was small. Each option increased the economic performance of the meso-level system by approx. 4-8 percent. This increase was due to several factors such as: i) increases in product output, ii) replacement of groundwater with water extracted from the milk, which is more economical, and iii) greater recirculation of water in the dairy plant, thus reducing the WW flow and the fees paid for WWT. Economic benefits would go mainly to the dairy, while the NEO would be lower for the water supplier, WWT utility and the biogas plant.

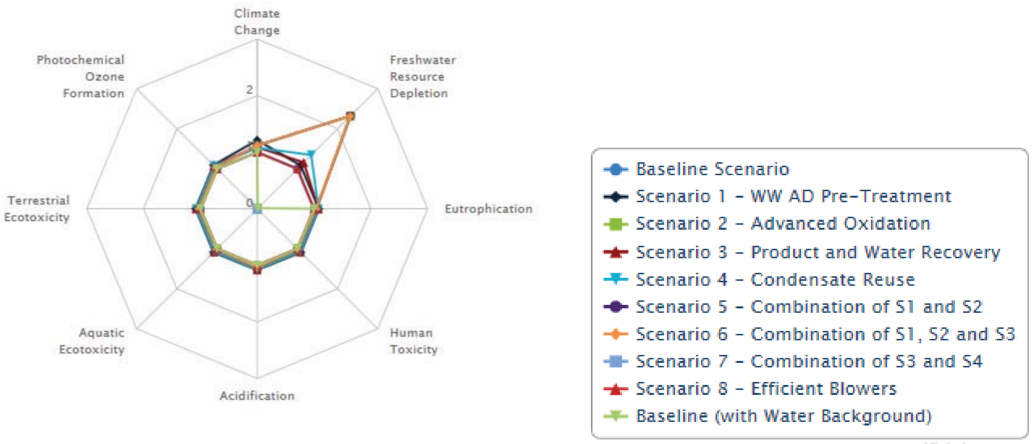

Figure 12: Eco-efficiency assessment of the five individual technologies and combinations

Combined options

Combinations of those options were also assessed (Figure 12). The greatest improvement in freshwater depletion would come from combining three options: anaerobic pre-treatment, advanced oxidation, and product & water recovery from CIP. A significant improvement would also come from condensate reuse alone.

Distributional Issues

Installation of the technologies or their combination of technologies would increase the total net economic output (NEO) by approximately. 4-8%.

For all technologies and their combinations, economic benefits would go mainly to the dairy, while there would be lower NEO for the water supplier, WWT utility and the biogas plant. The redistribution happens because the dairy's increased NEO results partly from lower fees paid for its water supply and WWT services to the water utility. Likewise the WW pre-treatment option shifts benefits from the biogas company to the dairy (D4.4). The latter example is shown in Table 5 (from Levidow et al., 2015).

Table 5 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 Env. Δ	Econ. + Env. +	Econ. + Env. +	Econ. - Env. -	Increase

9.3 Prospects for adopting eco-innovations

9.3.1 Influences on adoption: w*orkshop discussion*

Arla Foods' 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.

PESTLE analysis

The EcoWater team carried out a PESTLE analysis of Arla's potential innovations, based on researchers' contextual knowledge and discussions with stakeholders (D1.7). Some PESTLE factors were presented at the HOCO workshop, with an extra question: Who can influence the impact of drivers and remove or decrease barriers? (Lindgaard-Jørgensen, 2013b). This question had little time for discussion.

Workshop results

Held in September 2013, the 1st Arla HOCO workshop started with presentations on Arla's operations and approach to resource efficiency (Hansesgaard, 2013; Nørgaard, 2013). The CS team presented its systemic value-chain assessment of in-house WW pre-treatment, which would offer minimal benefits, as shown in the spider diagram of environmental parameters (Andersen, 2013). Stakeholders agreed with this assessment. 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.

At the workshop Arla representatives saw the EcoWater eco-efficiency tools as helpful for their decision-making to consider systemic effects. Several follow-up steps were proposed for discussions among DHI, Arla and the WWTP operator (Lindgaard-Jørgensen, 2013c; D6.2).

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 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.

By late 2014 the dairy had decided to invest in upgrading the CIP, which would allow product and water recovery, partly because this investment has a relatively short pay-back time. The dairy will apply for funds to document that advanced oxidation technology can achieve the microbial quality necessary to reuse the water (D4.4).

9.3.2 Policy implications

As described above, several improvement options would reuse water from within the plant process. These would reduce the dairy's water intake, greatly increase eco-efficiency of the freshwater-depletion indicator and somewhat reduce the climate-change indicator. Such reuse depends on food authorities accepting that the water in milk does not cause any risks to the products' consumers. Industry has had difficulty to gain such acceptance in some EU member states such as Denmark. Authorities refer to the EU requirement to use drinking water, as specified in the dairy-sector Bref document (CEC, 2005).

Its current ongoing revision should clarify that, under appropriate conditions, the water in milk can be safely used to a high degree and so replace freshwater intake. Several internal water streams in the dairy plant have low levels of contamination and so also could be used outside the dairy, e.g. for irrigating agriculture, replenishing groundwater, etc. The dairy industry should be considered as a sector with a large potential to reuse water safely for these purposes. The quality criteria and control mechanisms are being discussed for implementing the *Blueprint to Safeguard Europe's Water Resources*, whose objectives include 'maximisation of water reuse' (CEC, 2012b).

10 CS8 Volvo Trucks

10.1 Meso-level system

10.1.1 Eco-innovation context

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. The sector has incrementally improved the energy efficiency of the internal combustion engine. Since the 1990s some manufacturers have also developed alternative-fuel vehicles. The emphasis on resource-efficient vehicle use comes partly from EC legislation requiring that by 2015 CO_2 emissions from all new EU-registered cars should not exceed an average of 130g CO_2/km across the range of each manufacturer.

Going beyond product use, some automobile companies have also developed eco-innovation at manufacturing sites. Towards 'sustainable plants', Toyota has sought to reduce CO_2 emissions, e.g. through photovoltaic power generation systems substituting for fossil fuels. Walls and roofs are covered 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 at 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). In the short term, process redesign loses sunk investments in automobile production systems (Orsato and Wells, 2007).

Going beyond many other automobile 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, encompassing the production process:

> *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)*

Volvo Trucks elaborates its environmental perspectives on process upgrading:

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. We were the first company to build a carbon neutral factory. The plant in Umeå has the lowest solvent emissions across the industry, and we are working on more of our dealers to become carbon neutral. For future years, we plan to expand business globally to include as much as possible of the production. (*2013-08-26, original text in Swedish as translated by Google translate,* *http://www.volvotrucks.com/trucks/sweden-market/sv-se/aboutus/environment/Pages/environment.aspx*)

10.1.2 Eco-innovation upgrading as focus

To achieve its sustainability aims, Volvo attempts to redesign systems for more closed cycles:

Although much has been done, emissions can still be reduced by using virtual paint simulators. In simulators painting programmes that control how the machines work are optimised. Other solutions include closed recirculation purification systems and rethinking processes in order to reduce the amount of steps used in the production, *http://www.volvogroup.com/group/global/en-gb/researchandtechnology/sustainable_production/resource_efficiency/pages/resource_efficiency.aspx*

Volvo Trucks has been adopting or considering various eco-efficient processes. The company takes a holistic view of resources, emissions, quality, and safety. It attempts to 'Avoid-reduce-recycle' waste. Closed-loop systems have several advantages:

- More efficient treatment as the separation technique can be applied near source
- Easier recycling of treated water and process chemicals when applied near source
- Reduced amount of waste if process chemicals can be recovered.
- Energy can be recovered as the recycled water has the right temperature
- When operating in a more continuous mode the quality variations can be reduced
- Water recycling gives less emissions to recipient and less reporting and other interactions with authorities.
- Less need and reduced investment & running cost for end-of-pipe management.
- Operation of the water recycling equipment can be made as an integrated part of the rest of the process equipment and by the same personnel (Lindskog, 2013).

But closed systems also pose challenges:

- Quality parameters are not always adapted-optimized
- Monitoring has to be adapted
- Accumulation of unwanted elements

- Unwanted growth of microorganisms
- Contamination of particles and oils that re-deposit on the surface.
- Carry-in of fluids from upstream operations
- Drag-out of active chemicals with the product
- Increased salt content due to contaminants, evaporation and addition of chemicals
- Too early dumping due to non-optimized maintenance and monitoring routines (Lindskog, 2013).

10.1.3 Meso-level boundaries

The Volvo Group is structured by operations at several sites. 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. Figure 13 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 Recycling for WWT.

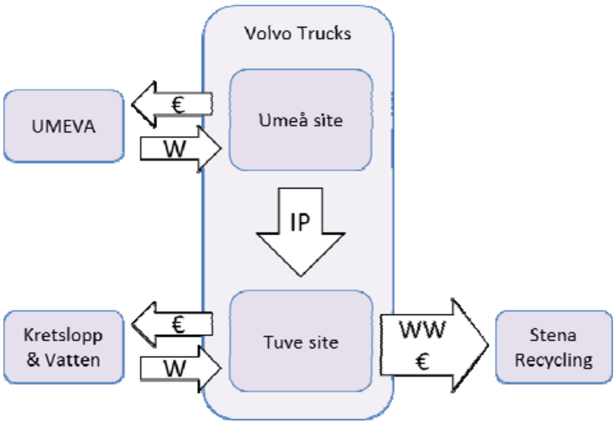

Figure 13 Volvo meso-level system Transactions between actors (€ = Economic, W = Water, WW = Wastewater, IP = Internal product (truck cabins), P = Product)

Meso-level actors were identified as follows (D4.1: 58-59, Tables 28 and 29):

- Directly involved actors: municipal water supply (UMEVA or Kretslopp & Vatten), Volvo Trucks and WWT (Stena Recycling in Goteborg case).
- Indirectly involved actors: regulatory authorities evaluating water quality, interpreting the WFD, specifying conditions of emissions permits, etc.; suppliers of WWT technologies; vehicle consumers; environmental NGOs, etc. (D4.1: 57).

Compared to the previous plan, system boundaries had two changes:

i. The system was extended to include the background processes for the production of electricity, district heating and chemicals. This allows the estimation of the background environmental impacts in addition to the impacts from the foreground processes.

ii. In addition to the total flows of chemicals used in the production stage, scarce elements (P, Ni and Zn) in the chemicals were also accounted. This is necessary in order to evaluate the contribution to resource-depletion environmental indicators. The data records of those elements (e.g. P) can be seen a simplification for calculating indicators. The actual amount of chemicals used (including the elements P, Ni and Zn) are also recorded (D2.2: 40).

10.2 Eco-efficiency assessment

10.2.1 Baseline assessment

Data came mainly from the companies. Background impacts of industry-specific chemicals came from open access LCA databases. Municipal water treatment was modelled with data for water treatment from the LCA database Ecoinvent GaBi4 (D4.2: 43).

From the baseline assessment, the water-using stages at both sites are the environmentally weakest. The Umeå pre-treatment step is metal surface treatment before painting, including degreasing and methods for corrosion protection. For Tuve's corrosion-protection process, current phosphating technology requires heating of process baths, uses heavy metals (Zn, Ni, Mn) which end up in WW, and produces hazardous sludge (metal hydroxides).

Main resource burdens are: aquatic ecotoxicity due to heavy metals at the WWT stage but likewise due to the chemical-process water-use stage, and eutrophication mainly due to phosphorus in WW after the corrosion protection process (thus approx. half from the foreground). Also important is resource depletion of scarce elements (P, Ni and Zn) in the foreground.

Therefore new technologies should prioritise these aims (D4.2: 55).

- Reduce water use, which would also reduce electricity use for pumping in the whole system,
- Reduce energy used for heating,
- Reduce the use of scarce elements in chemicals,
- Reduce the use of elements that become toxic pollutants in the wastewater,
- Reduce the use of elements that become nutrients in the wastewater, causing eutrophication.

10.2.2 Technology options comparison

Apart from water-cooling systems, the automotive industry uses the largest amount of water at the stages of metal-surface treatment (for corrosion protection) and the painting lines (except for those using powder coatings). Initially the case study considered a wide range of technologies at three production stages – water purification, water use and WWT (D4.1: 63-64). Later the study decided to focus on fewer options, in particular:

- Membrane distillation as an alternative to reverse osmosis in the WWT stage (at Umeå and Tuve sites);
- Electro-deionisation as an alternative to cleaning incoming water for industrial processes (at Umeå site);

- Silane-based metal-surface treatment as an alternative to the current phosphating technique for corrosion protection (at Tuve site);
- Recirculation of process water and chemicals by partly cleaning the rinse water from degreasing and phosphating (at Umeå site).

Eco-efficiency comparisons of those four options:

- Technology comparison: The latter two options (both in the water-use stage) show the highest eco-efficiency improvement.
- TVA comparison: TVA is lower than the baseline for most options, mainly because the investment costs are high.
- TVA distribution: For the 3rd option, the TVA is higher than the baseline, because the silane-based option uses the same process infrastructure as the current phosphating technique, and the extra TVA goes to the industrial company.
- Basis of eco-efficiency change: Technology options lower resource burdens in the eco-efficiency denominator; eco-efficiency indicators were variously higher or lower than baseline, mainly depending on the cost of each option (D4.4).

As above, the highest eco-efficiency gain comes from the silane-based option, partly because it requires no extra investment. This option offers the following benefits:

- Resource efficiency by saving energy, water and use of scarce elements;
- Less hazardous waste, especially sludge with high metal content;
- Less pollutants in the wastewater (e.g. P, Ni and Zn);
- Lower operating costs (resulting from the first two points above).

Distributional Issues

As noted above, the silane-based option increases the TVA. The extra goes mainly to Volvo because the Tuve site would pay the water-supply company for less water; more significantly, it would pay the WWT company Stena for less WW to treat. Both water companies would lose income and NEO, especially Stena, as shown in Table 6 below.

Table 6 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. = Env. =	Econ. - Env. +	Econ. + Env. +	Econ. - Env. +	Increase

10.3 Prospects for adopting eco-innovations

10.3.1 Influences on adoption: *workshop discussions*

Organisational responsibilities: The Tuve and Umeå sites are separate units responsible for their own economic value and environmental impact. Economic and environmental evaluation is currently made separately by each site, not for an overall system of production sites. At each Volvo site, different units have responsibility for environmental and economic evaluation, with some discussions between them. Volvo integrates environmental and economic targets within a common process, especially for climate change and energy use, according to the company (Personal communication, Lars Mårtensson, 2013). Volvo and WWT companies have no systematic discussion about eco-innovation. So fragmented responsibilities impede or complicate an overall meso-level eco-efficiency analysis, as a basis to identify optimal solutions. Such a discussion was stimulated by the EcoWater case study.

Held in March 2013, the first Gothenburg workshop brought together representatives from Volvo Technology (VTEC), Volvo Trucks, Stena Recycling (the latter's contractor for WWT) and the Swedish Agency for Marine and Water Management (HaV). According to the VTEC representative, 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 [D6.1: 33-34].

Closed-loop systems have several advantages but also disadvantages (Lindskog, 2013). As a general point from the VTEC representative, resource-efficiency benefits depend on the overall process design as well as the technology.

He mentioned two options for improvement: the electro dip coating (cataphoresis) step, which can become more efficient by recycling the paint through an ultrafiltration unit; and phosphating technology in corrosion protection can be replaced with a new silane-based technology, Oxsilane. The latter would have several advantages, allowing 'lower resource consumption and less waste' (Lindskog, 2013). Oxsilane has undergone pilot testing but needs to demonstrate sufficient protection for trucks: 'The examined technology improves the eco-efficiency of the system', but only when it works adequately (D4.1: 35-36).

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 – e.g. variable rate, flat rate, fee for extra pollution [D6.1: 35-36].*

The case-study team presented its meso-level eco-efficiency analysis of the silane-based option. In the discussion a VTEC participant noted: When evaluating eco-efficiency of a technology, taking a systemic perspective will reduce the risk of sub-optimal solutions.

After the case-study team explained the PESTLE method to workshop participants, small-group discussions considered relevant factors under the six categories. Key points were summarised in a Table (D6.1: 45-46). Drivers include policy-legislative factors, e.g. R&D funds, EU water policy, hazardous waste policy, etc.

In one sub-group, standards for Best Available Technology (BAT) were seen as a potential driver and/or barrier. Although BAT standards have provided a common EU-wide minimum, future uncertainty potentially serves as a limit of eco-innovation. For corrosion-protection 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 silence illustrates, companies face uncertainty about whether the authorities will accept such alternative as 'best available' technology.

Important conclusions of the workshop were [D6.1: 37-38]:

- The proposed silane-based technology can potentially improve the eco-efficiency of the Volvo Trucks water system.
- Water recycling is a promising option for improving the performance of water-consuming production processes; Volvo Trucks have already introduced water recycling in production, e.g. counter-current flow of process water using effluent water of "cleaner" process steps as input to "less clean" steps and recycling process water through ultra-filtration. Further improvements, especially new solutions for increased water recycling, still interest Volvo Trucks.
- 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.
- Local stakeholders have shown significant interest in the EcoWater eco-efficiency concept and results; colleagues of the workshop participants also expressed interest in being involved in similar EcoWater events.

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

At that workshop an interactive exercise explored barriers and drivers of potential improvements by discussing the six standard PESTLE factors. The results identified three of the most important factors as follows: Economic: electricity price; Environmental: use and regulation of persistent chemicals; Political: policy on scarce resources (phosphorous, metals). The exercise anticipated plausible variations in their future states and how these may drive or impede Volvo's implementation of eco-innovative technologies. A follow-up exercise could analyse the need for specific policies to promote eco-innovation across the various potential futures.

In sum, the multi-stakeholder workshops served as a good starting point for further discussions. The meso-level evaluation of technologies served as a tangible way to stimulate discussion. It also gave stakeholders greater insight into where the largest improvements can be made, both environmentally and economically, and how they may influence each other within a common meso-level system. Conducting a PESTLE analysis in a multi-stakeholder group is a method to ensure discussion of all factors.

10.3.2 Policy implications

As above, the EU's relatively stringent pollution standards have generally driven eco-innovation.

For process improvements at Volvo, an important driver is the prospect of more stringent pollution standards, especially regarding the use of persistent chemicals and of scarce metals.

As regards BAT standards for corrosion protection, the relevant Bref document briefly mentions silane-based alternatives, without evaluating them (CEC, 2006). Consequently, the company remains uncertain about whether the authorities will accept the silane-based alternative as 'best available' technology. The future uncertainty may deter such investment. Clearer, updated EU standards would help to guide national regulators and reassure manufacturing companies.

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11.1 EcoWater deliverables cited: list

D 1.1: Review and selection of eco-efficiency indicators to be used in the EcoWater Case Studies (2012),

D 1.2: Value chain mapping of the agricultural water systems (2012).

D 1.7: Methodology and scenario frameworks for elaboration in the EcoWater Case Studies (2012).

D 1.8: Roadmap for Case Study Development (2012). [Restricted dissemination level]

D 2.1: Description of value chains for agricultural water use: Case Studies 1-2 (2012).

D 2.2: Baseline eco-efficiency assessment of water use in agricultural sectors: Case Studies 1-2 (2013).

D 2.3: Innovative technologies for enhancing the eco-efficiency of agricultural sectors (2014)

D 2.4: Technology assessment and scenario analysis for agricultural studies (2014 draft).

D 3.2: Baseline eco-efficiency assessment of water use in urban sectors: Case Studies 3-4 (2013).

D 3.4: Technology assessment and scenario analysis for urban studies (2014 draft).

D 4.1: Description of value chains for industrial water use (2012).

D 4.2: Baseline eco-efficiency assessment of water use in industrial sectors: Case Studies 5-8 (2013),

D 4.3: Innovative technologies for enhancing the eco-efficiency of water use in industries: Case Studies 5-8 (2014)

D 4.4: Technology assessment and scenario analysis for industry case studies (2014 draft).

D 6.1: Synthesis report from the 1st Round of Case Study events (2013)

D 6.2: Synthesis report from the 2nd Round of Case Study events (2014)

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