Adaptation to Climate Change in Industry: Improving Resource Efficiency through Sustainable Production Applications

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ABSTRACT: The objective of this study was to investigate the climate change adaptation opportunities of six companies from different sectors through resource efficiency and sustainable production. A total of 77 sustainable production options were developed for the companies based on the audits conducted. After screening these opportunities with each company's staff, 19 options were selected and implemented. Significant water savings (849,668 m^3/year) were achieved as a result of the applications that targeted reduction of water use. In addition to water savings, the energy consumption was reduced by 3,607 MWh, which decreased the CO_2 emissions by 904.1 tons/year. Moreover, the consumption of 278.4 tons/year of chemicals (e.g., NaCl, CdO, NaCN) was avoided, thus the corresponding pollution load to the wastewater treatment plant was reduced. Besides the tangible improvements, other gains were achieved, such as improved product quality, improved health and safety conditions, reduced maintenance requirements, and ensured compliance with national and EU regulations. To the best of the authors' knowledge, this study is the first ever activity in Turkey devoted to climate change adaptation in the private sector. This study may serve as a building block in Turkey for the integration of climate change adaptation and mitigation approach in the industry, since water efficiency (adaptation) and carbon reduction (mitigation) are achieved simultaneously. *Water Environ. Res.*, **87,** 14 (2015).

KEYWORDS: climate change adaptation, business, water saving, cleaner production, eco-efficiency, environmental performance.

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Introduction

The most recent report of the Intergovernmental Panel on Climate Change (IPCC) confirms that the climate is changing across our planet, largely as a result of human activities (Cubasch et al., 2013). A wide range of climate change impacts and risks were identified by IPCC for different regions of the world. One of the major impacts is related to water. All IPCC regions show an overall net negative impact of climate change on water resources and freshwater ecosystems. Several major carbon stocks in terrestrial ecosystems are also vulnerable to current climate change (IPCC, 2007). The IPCC report emphasizes that climate change can potentially have a large impact on the global water cycle by modifying precipitation and evaporation patterns. This is likely to have a significant effect on water availability (Ludwig et al., 2009; Bates et al., 2008).

According to the report, even if all greenhouse gas emissions are reduced to pre-industrial levels tomorrow, the effect of today's level of greenhouse gases is predicted to produce change in the climate system for the next 40 years (SCCIP, 2010). Based on the serious impacts and risks associated with climate change, adaptation has been widely recognized as an equally important and complementary response to greenhouse gas mitigation (Agrawala et al., 2011).

Whereas mitigation refers to the actions that reduce exposure to change (e.g., through regulation), location, and technological shifts, adaptation refers to the adjustments of a population in response to current and predicted change (Nelson et al., 2007). Mitigation has been regarded mainly as a task for national governments; however, adaptation has been primarily a matter of regional and local scale (The German Federal Government, 2008; UNFCCC, 2013). While mitigation efforts mainly produce public benefits, adaptation mainly produces private benefits (Tol, 2005).

In this regard, the role of private sector in adaptation is critical. A country's success at adaptation depends on the success of the private sector in responding to climate change impacts and risks. Additionally, private sector responses may provide lessons and examples of innovative approaches of interest to the public sector (Agrawala et al., 2011). Climate change impacts constitute one of the major risks that the businesses presently face. Busch (2011) underlines that businesses should acknowledge the strategic relevance of climate change and accelerate their efforts to develop and deploy capabilities required for the adaptation process.

Consequently, businesses have to reduce emissions to the environment and at the same time adapt to inevitable climate change that is already built in. Complementary action on both reduction and adaptation needs to be taken (SCCIP, 2010). Adaptation measures can only be successful if they are combined with mitigation efforts, because doing so helps businesses lower the need for adaptation. More options for strategic combinations of both should be considered (Beermann, 2011).

This approach is supported by the results of a survey carried out by OECD on 16 companies to measure their actions towards climate change adaptation (Agrawala et al., 2011). According to this survey, a majority of the companies prefers to implement "no regret" or "soft" measures, which are synergistic measures

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that are also beneficial to general business operations and address current climate and environmental concerns. Examples of such synergistic measures can be found in several industry sectors and typically address issues such as water scarcity and sourcing of raw materials for production. Within this framework, there is a particular focus made on water scarcity, since it is a growing concern for businesses. Companies across almost all industry sectors observe decreases in water allocations, more stringent regulations, and higher costs for water usage. In this respect, water recycling, reusing water from a tailings dam, and minimization of evaporative water losses are regarded as examples of adaptation measures.

These examples reveal how an industry's climate change adaptation links with sustainable production applications and resource efficiency, particularly water conservation. Resource efficiency is also a strategy that combines climate change mitigation and adaptation. While resource-efficient activities directly reduce greenhouse gas emissions, they also help businesses adjust to present and future problems associated with climate change, such as resource scarcity and price increases.

Located in the Mediterranean Basin and especially vulnerable to the adverse impacts of climate change (IPCC, 2007), Turkey has recently adopted its Climate Change Strategy for 2010–2020 (MOEU, 2012). This national strategy aims to increase national preparedness and capacity in order to avoid the adverse impacts of global climate change and to adapt to these impacts. Both mitigation and adaptation aspects are included within the scope of the strategy. One of the goals is to develop national research and development (R&D) and innovation capacity towards cleaner (sustainable) production. Particularly for adaptation, scientific studies on the sustainable use of natural resources are planned to continue, taking into consideration the interaction between climate change and industrial sectors. Furthermore, studies are planned for volume-based water pricing to ensure protection and efficient use of water resources. Rainwater capture, use, and recycling are other practices considered for achieving water efficiency.

The aim of this study was to investigate the resource efficiency and sustainable production opportunities in six different companies in Turkey, as a way to contribute to their climate change adaptation efforts. At each of the companies, all of which operate in a different sector, a walk-through audit was initially carried out. After the environmental performance evaluation and benchmarking studies, opportunities for sustainable production were assessed. Within the scope of climate change adaptation, 19 sustainable production opportunities—most of which focus on water conservation—were selected and implemented. This study is expected to be a model for different industries to develop and implement sustainable production applications as climate change adaptation measures, combined with their mitigation related activities. It is expected that the outcomes will also be useful for the implementation of Turkey's Climate Change Strategy. To the best of authors' knowledge this is the first study in Turkey that is devoted to adaptation to climate change in the private sector.

The study was carried out within the framework of the national "Eco-efficiency (Cleaner Production) Programme," which was coordinated by the United Nations Industrial Development Organization (UNIDO) and implemented by Technology Development Foundation of Turkey (TTGV). Technical consultancy was provided by Middle East Technical University. The program was implemented as a sub-program of the United Nations Joint Program "MDG-F 1680: Enhancing the Capacity of Turkey to Adapt to Climate Change." Further information about the "Eco-efficiency (Cleaner Production) Program" can be retrieved from its web page (http://www.ecoefficiency-tr.org/). Within the scope of the program, two studies were previously published for metal processing (Alkaya and Demirer, 2013a) and woven fabric manufacturing (Alkaya and Demirer, 2013b) industries.

Methodology

General Information about the Investigated Companies. Company A was established in 1960 in Adana, Turkey, and started its activities in agricultural products processing and fields exporting. In 1975 Company A integrated seafood processing into its field of activities. Since then, seafood processing (Nace code: C.10.2.0—Processing and preserving of fish, crustaceans and mollusks) has become the major field of activity for the firm, which currently has 120 employees. Marinated products (e.g. anchovy, shrimp) and frozen products (e.g. escargot, squid) are Company A's main products.

Company B was established in 1969 in Kayseri, Turkey. Currently, production of soft drinks and beverages (Nace code: C.11.0.7—Manufacture of soft drinks; production of mineral waters and other bottled waters) is Company B's main field of activity. It maintains its operations in a covered area of 15,000 m^2 and has 100–130 employees, depending on the season. Major products of the company can be listed as: (i) 100% fruit juice (no additives), (ii) fruit nectar (25–50 % fruit juice) and (iii) fruit drink (3–30% fruit juice).

Company C was established in 1972 in Niğde, Turkey. Company C operates in the metal processing and machinery sector as a supplier for the automotive industry (Nace code: C.29.3—Manufacture of parts and accessories for motor vehicles) and operates in a covered area of 20,000 m^2. With 358 employees, it produces various parts and accessories for motor vehicles, including, tie rods, stabilizer links, ball joints, and V-torque rods.

Company D was established in 1966 in Adana, Turkey. It is active in the chemical products sector (Nace code: C.20.6—Manufacture of man-made fibres) by producing polyester fibers, filaments, various polymers, and intermediate chemicals, including thermoplastic polyester elastomers (TPE) and dimethyl terephthalate (DMT). Company D is regarded as one of the biggest polyester producers in the world, with more than 1,200 employees, a production area of 1,000,000 m^2, and 750 tons/day DMT production capacity.

Company E was established in 1940. Since 2003 it has been producing woven fabrics for women's clothing (Nace code: C.13.2—Weaving of textiles) in its production facility, located in Bursa. With 147 employees, Company E operates in a covered facility of 10,000 m^2. The company produces various kinds of fabrics, including polyester, cotton, and lycra-based fabrics.

Company F was established in 1996 in Ankara, Turkey. It currently provides metal coating and painting services (Nace code: C.25.6.1—Treatment and coating of metals) to various kinds of firms—from military and aerospace to the automotive sector. It operates in a covered area of 1,350 m^2 and has 12 employees. Company F's services include surface treatment and coating, as well as wet and electrostatic powder painting of aluminum, ferrous materials, and other metal alloys.

Data Collection and Environmental Performance Evaluation. In each company, an initial walk-through audit was carried out with company officials before detailed process-based numerical data was gathered. As a result of these half-day walk-through audits, which provided information on inputs and outputs of major processes, process flow diagrams were developed for each company. Since the objective of the study was to increase environmental performance and decrease manufacturing cost in each company, resource-intensive and polluting processes/practices were investigated. Monthly resource consumption, waste/emission generation data, and associated expenditures were compiled from different sources provided by the staff of the companies. Information sources like process-based record sheets as well as water/energy/chemical bills were analyzed. Informative catalogs of equipment and material safety data sheets (MSDS) of chemicals were also collected and analyzed.

Environmental Performance Evaluation (EPE) was carried out by using the data collected before sustainable production applications. As described by the International Organization for Standardization (ISO), "environmental performance evaluation is a process to facilitate management decisions regarding an organization's environmental performance by selecting indicators, collecting and analyzing data, and assessing information against environmental performance criteria." (Dias-Sardinha and Reijnders, 2001.) In order to identify which processes/practices need to be improved in manufacturing enterprises, environmental performance evaluation methodologies have been developed and have been widely used in various sectors (Jiang, Zhang, and Sutherland, 2012).

Environmental benchmarking was carried out using Environmental Performance Indicators (EPIs) that are specific resource consumption and waste/emission generation data. According to Thoresen (1999), EPIs can be used by industrial enterprises to control performance of processes, set goals, and compare the performance with competitors. In this study EPIs were calculated by dividing resource consumption or waste/emission generation data by manufactured products or processed raw materials, depending on the data provided by the associated companies. Then, the specific resource consumption and waste/emission generation data was used for environmental benchmarking with relevant literature.

Opportunity Assessment and Implementation of Selected Options. As a result of environmental performance evaluation, the objectives were set for each company to decrease the negative environmental impacts and production costs associated with high impact processes/practices. To achieve these objectives, 77 options were developed for six companies.

In order to find best possible and applicable solutions among the 77 options, an opportunity assessment phase was carried out with company officials. The first step of this phase was the determination of "assessment criteria." Assessment criteria were determined by referring to five studies in the literature (Barros et al., 2008; European Commission, 2006a; Kliopova and Bagdonas, 2003; Pandey, 2007; UNEP, 2004). In these studies, whenever sustainable production options are evaluated, the following criteria were recommended:

- Environmental requirements, adaptability to employed processes, quality requirements, occupational health and safety requirements, (Kliopova and Bagdonas, 2003)
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- Applicability of the technology, economical feasibility, examples of successful applications, level of technology (UNEP, 2004)
- Environmental benefit, complexity of the application, cost saving, scale of innovation, effect on processes/products (Pandey, 2007)
- Achieved environmental benefits, economics, operational data, applicability, examples of successful applications, cross-media effects (European Commission, 2006a)
- Environmental aspects, applicability and characterization, economic aspects, plants where the technique is already implemented, secondary effects (Barros et al., 2008)

Referring to the above-listed studies, seven assessment criteria were determined as follows:

- Environmental benefits
- Technical applicability
- Economic viability
- Ease of implementation
- Long-term sustainability
- Operational and maintenance requirements
- Cross-media effects

As a result of the opportunity assessment, the 19 options listed below were selected and implemented within the companies (Table 1).

Results and Discussions

Seafood Industry (Company A). Anchovy processing makes up for the highest water consumption (4,831 m^3/month) in Company A. It corresponds to 77.3% of total water consumption in the company. Anchovy thawing and gutting are the sub processes of anchovy processing and are responsible for 48.0% and 29.3% of total water consumption, respectively. By taking into account these values, as well as the results of benchmarking analysis (Table 2), the total specific water consumption of the company for anchovy processing (74.9 m^3/ton raw fish) was determined to be significantly higher than the reported values in the relevant literature (1.0–32.0 m^3/ton raw fish). It should be noted that processing of other fish products requires far less water (21.5 m^3/ton raw fish) than anchovy processing. A more detailed investigation on the anchovy processing indicated that the company consumes water intensively in thawing and gutting processes. Although environmental benchmarking was carried out separately for each company, only the benchmarking for Company A was presented as an example in this study (Table 2).

In order to reduce the amount of water consumption in Company A, three measures were implemented as sustainable production applications. As a result of these applications, the water consumption of the company was reduced significantly in both the anchovy thawing and gutting processes. In the thawing process, specific water consumption was reduced from 28.4 to 10.0 m^3/ton raw fish, which corresponds to a water savings of 64.9%. In the gutting process, even higher percentages (77.2%) of water savings were achieved. In the baseline situation, the specific water consumption of the thawing process was recorded as 46.5 m^3/ton raw fish, which was decreased to 10.6 m^3 per processed raw fish with related applications. The water

Table 1—Sustainable production applications realized in the companies.

Industrial sectors (companies)	Sustainable production applications
Seafood (Company A)	Recycle the thawing water through a closed-circuit water recirculation system (Archer et al., 2008; European Commission, 2006a)
	Treat and reuse the wastewater generated in the gutting process (Bugallo et al., 2013; Cappell et al., 2007; European Commission, 2006a; Hall, 2010; UNEP, 2004)
	Separate/segregate solids, fats, and oils from waste streams for valorization of by-products and reduction of pollutant load (Barros et al., 2009; ETBPP, 1999; Hall, 2010; Thrane et al., 2009)
Soft Drink/Beverage (Company B)	Replace once-through cooling system with closed-circuit cooling system in fruit concentrate and fruit juice production lines (Casani and Knchel, 2002; European Commission, 2006b; WRAP, 2013).
	Reuse cooling water blow-down in fruit washing process (Envirowise, 2002; European Commission, 2001; NCDENR, 2009a).
Metal Processing (Company C)	Recycle the spent cooling water generated in heat treatment process to main water supply tank of the company (Van Berkel, 2007)
	Increase the drip (drainage) time above process baths to decrease drag-outs (Hunt, 1988; FDOEP, 2006)
	Place drain boards between process tanks to prevent drips from workpieces to the floor and recover drag-outs (Dahab and Lund, 1994; Barros et. al., 2008; NCDENRb, 2009; RAC/CP, 2002)
	Divide rinsing tanks into two stages and apply counter current rinsing using two consecutive rinsing stages (RAC/CP, 2002; European Commission, 2006a; Reeve, 2007; Barros et. al., 2008)
	Install covers on top of tanks to prevent evaporation losses of chemicals, water and energy (USAID, 2009)
Chemical (Company D)	Substitute water-cooled heat transfer pumps with air-cooled centrifugal pumps (Arneth and Dötsch, 2006; CIRAS, 2005; Environment Agency, 2003; Werner, 2006)
	Substitute "EFF-3 Standard Efficiency" class motor mounted heat transfer pumps with "EFF-1 High Efficiency" class motor mounted pumps (European Commission, 2001)
Textile (Company E)	Use drop-fill washing instead of overflow (ETBPP, 1997; European Commission, 2003; NCDENR, 2009c; Shaikh, 2009)
	Reuse stenter cooling water (European Commission, 2003; NCDENR, 2009c; Shaikh, 2009; Greer et.al., 2010; Chougule and Sonaje, 2012)
	Reuse singeing cooling water (European Commission, 2003; NCDENR, 2009c; Shaikh, 2009; Greer et.al., 2010; Chougule and Sonaje, 2012)
	Renovate water softening system (ETBPP, 1997; Kalliala and Talvenmaa, 2000; European Commission, 2003)
	Renovate various valves and fittings in water transmission system (European Commission, 2003; NCDENR, 2009c; Greer et.al., 2010)
Surface Coating/Painting (Company F)	Replace chemical/labor intensive solvent based degreasing (hand wiping) process with alternative degreasing practices (Envirowise, 2003; European Commission, 2006a)
	Substitute cadmium plating process with a less toxic and more environmentally friendly alternative coating process (European Commission, 2006a; Heimann and Simpson, 2005; RAC/CP, 2002; USAID, 2009)

consumption was reduced by 72.6 % in the anchovy processing line of the company. Since anchovy processing is the major operation of the company, sustainable production applications also had considerable impact on the entire water consumption of the company. Annual total water savings of the company was calculated as 29,002 m^3 corresponding to 45.0% (as m^3/ton product). Another major outcome of these applications was the production of valuable by-product in the form of fish oil/grease from gutting wastewater. Since implemented water treatment and recycling systems enable the separation and segregation of fish oil/grease from the wastewater, 140 kg/month of fish oil/grease was produced as a by-product. Organic load of wastewater was also reduced by decreasing the oil/grease content of the wastewater by 47.3 mg/L.

When the economic feasibility of the indicated applications is considered, the total investment cost for the equipment was $76,900 . On the other hand, the annual water and energy savings of the applications are calculated as $48,175. The payback period of the corresponding implementations is 1.6 years.

Soft Drink/Beverage Industry (Company B). A once-through cooling system had been used in fruit concentrate and fruit juice production units in Company B before this study. Average cooling water consumption of the company was 14.5 m^3/m^3. In various studies it is suggested that once-through cooling practices should be replaced by closed-circuit cooling systems in the soft drink/beverage industry (Casani and Knchel, 2002; European Commission, 2006b; WRAP, 2013). According to the European Commission (2006b), up to 80% of water can be saved by eliminating the once-through cooling practice and introducing closed-circuit cooling. Moreover, cooling water blow-down can be reused in other processes, including fruit washing and facility cleaning (Envirowise, 2002; European Commission, 2001; NCDENR, 2009a). Therefore, in the framework of sustainable production applications in Company B, once-through cooling systems in fruit concentrate and fruit juice production units were replaced by separate closed-circuit cooling systems (Figure 1). Each closed-circuit cooling system was composed of a cooling tower, stainless steel water pumps, stainless steel pipes/fittings, variable speed drivers (inverters) and a control panel.

After implementation of cooling-water recycle and reuse systems, the total cooling water consumption of the company was decreased by 91.8 % and decreased to 1.2 m^3/m^3 product. As a result of these applications, the specific cooling water consumption in fruit concentrate production lines was reduced by 95.2 %, from 9.6 to 0.5 m^3/m^3 product. Moreover, specific cooling water consumption was reduced from 4.8 to 0.7 m^3/m^3 product, which corresponds to a decrease of 85.2%. Therefore, the total cooling water demand of the company was reduced by

Table 2—Benchmarking of environmental performance of the Company A (Seafood Industry) with related literature.

Seafood product	Total specific water use (m^3/ton raw fish)	Specific water use in thawing (m^3/ton raw fish)	Specific water use in gutting (m^3/ton raw fish)	Specific energy use (kWh/ton raw fish)	Specific solid waste generation (tons/ton raw fish)	Reference
Jack mackerel	1.8	-	-	117	0.29	Bezama et. al, 2012
Herring	1.0–3.4	-	-	-	-	Thrane et al., 2009
Canned tuna	13.0	0.7	-	-	0.38	Uttamangkabovorn et al., 2005
Canned tuna	17.8	-	-	-	-	Nair, 1990
Canned sardine	9.0	-	-	-	-	Proenca et al., 2000
Not specified	8.9	-	-	-	0.55	Nimnu, 1998
Not specified	-	3.7–5.6	-	-	0.66	Knuckey et al., 2004
Pilchard	-	12.0	-	-	-	EPA, 2001
Canned fish	9.0–16.0	-	-	397	0.47–0.60	Visvanathan, 2007
Not specified[a]	5.0–11.0	-	-	91–638	-	IFC, 2007
Whitefish	9.5–24.0	-	5.0–7.4	-	-	Cappell et al., 2007;
Not specified[b]	3.3–32.0	1.0	-	-	0.20–0.60	European Commision, 2006b
Not specified	20.4–24.1	-	-	-	0.20–0.50	RAC/CP, 2001
Not specified[c]	1.0–15.0	5.0	5.0–11.0	62–190	0.50–0.70	UNEP, 2000
Whitefish and herring	5.0–24.0	4.5–16.6	5.0–7.4	-	-	ETBPP, 1999
Anchovy	74.9	28.4	46.5	434	0.39	This study
Not Specified[d]	21.5[e]	-	-	5,554[e]	0.40	

[a] includes whitefish, herring, mackerel and fish-meal.
[b] includes whitefish, herring, mackerel and shrimp.
[c] includes whitefish, herring and tuna.
[d] includes shrimp, escargot and squid.
[e] calculated per ton of product.

91.8%. Recycle and reuse of cooling water enabled the company to conserve 55% of total water usage. Thus, the total annual water savings was calculated to be 503,893 m^3 by multiplying specific total water savings (13.0 m^3/m^3 product) with annual production of 38,761 m^3 product.

The European Commission (2006b) advocates that the discharge of once-through cooling waters causes dilution and increases energy consumption in wastewater plants, and should thus be avoided. Before this study, there was a seasonal increase in total water consumption of the company resulting from the increased cooling water demand. This situation was creating a hydraulic overload in the wastewater treatment plant of the Kayseri Organized Industrial Zone, the major wastewater producer of the zone with 67,411 m^3/month of discharge. After applications, specific wastewater generation of the company was reduced by 57.4% and hydraulic overload issues in the wastewater treatment plant were resolved.

When the economic feasibility of the indicated applications was analyzed, it was determined that the total investment cost for the equipment was $56,960. On the other hand economic return of annual water savings was calculated as $97,003, which makes the payback period of implementation 7 months.

Metal Processing Industry (Company C). The wastewater discharge of 6.44 L/piece of product in heat treatment process was completely eliminated by installing a water recycling system ,which corresponded to an average water savings of 2,211 m^3/month. Moreover, the reduction in cooling water consumption led to a significant decrease in the total water consumption of the company from 13.42 to 8.85 L/piece of product after applications.

Full-scale applications from different surface finishing plants proved that replacing single rinsing with multiple stage counter-current rinsing is a very successful measure for water savings and does not decrease rinsing-ratio (European Commission, 2006a; Reeve, 2007; Barros et. al., 2008). Hunt (1988) claims that 90–97 % of water use can be reduced by introducing two counter current rinse tanks instead of a single rinse. Similarly, NCDENR (2009b) advocates that rinse water consumption can be reduced by more than 90% by adding a second counter flowing rinse to a single rinse tank. Improving rinsing efficiency is a significant water reduction alternative for surface finishing processes (NCDENR, 2009b). Therefore, implementation of multi-stage counter-current rinsing (Figure 2) was implemented in Company C. It reduced the specific water consumption of total specific zinc phosphating by 80.4%, or from 0.95 to 0.19 L/piece of product on average. This value corresponded to a decrease in water requirement by 261 m^3/month in the zinc phosphating process.

Three major type of chemicals were used in the zinc phosphating process of Company C, namely (i) degreasing, (ii) pickling, and (iii) coating chemicals. Applying measures with respect to reducing drag-out losses, as well as rinsing water consumption, resulted in considerable decreases in the consumption of each of these chemical groups. When compared to baseline situation, specific degreasing, pickling, and coating chemical consumption was decreased by 17.0, 13.0 and 40.2%, respectively. As a result, total specific chemical consumption in the zinc phosphating process was reduced from 1.32 to 0.98 g/piece of product on average, which corresponded to a reduction of 26.1%.

As a result of these applications, the total water consumption of the company was reduced by 34.1%, corresponding to annual water savings of 18,831 m^3. Moreover, the total chemical consumption in zinc phosphating, which is one of the most

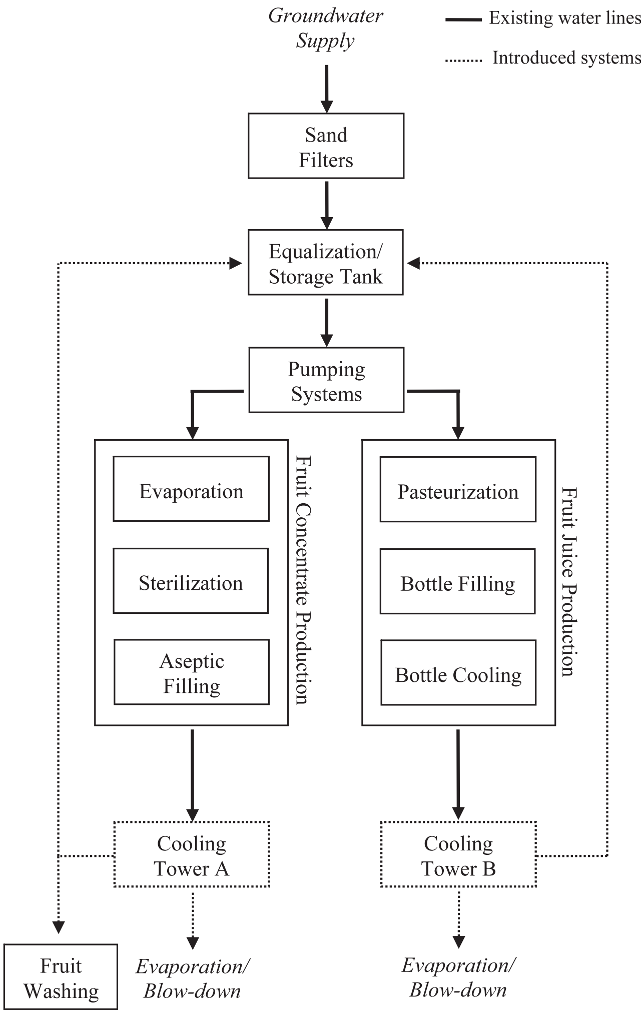

Figure 1—Recycle and reuse scheme of cooling water after applications in Company B (Soft Drink/Beverage Industry).

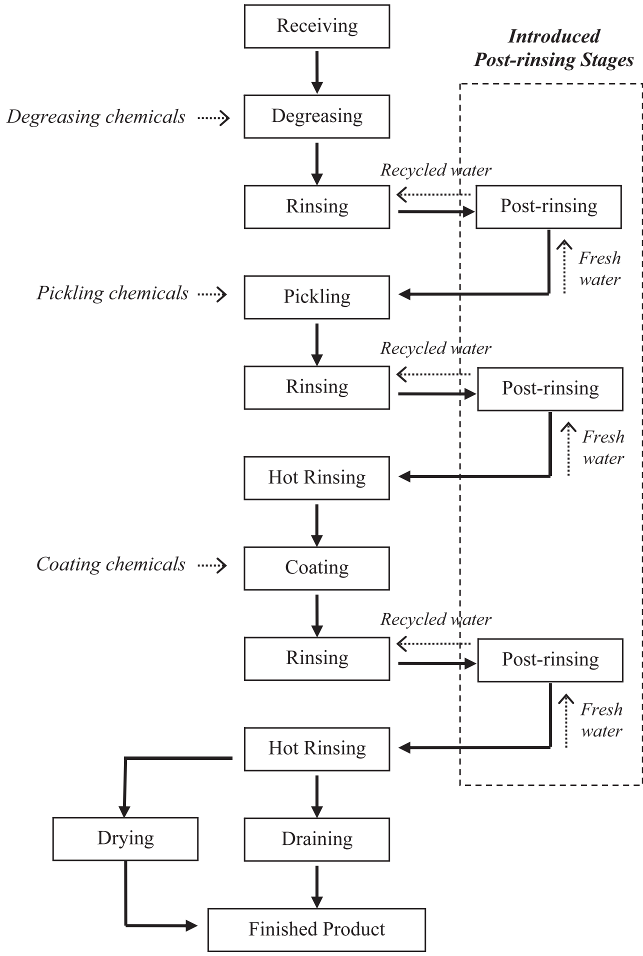

Figure 2—Process flow diagram in zinc phosphating after process modifications in Company C (Metal Processing Industry).

chemical intensive processes in the company, was decreased by 1,401 kg/year (26.1%). Applications in the zinc phosphating process led to a significant decrease in the amount of treated wastewater and wastewater treatment sludge, which is hazardous waste, according to national legislations. The total wastewater generation was decreased by 3,255 m^3/year (50.9 %), while wastewater treatment sludge was reduced by 4,656 kg/year (16.9%). Moreover, energy consumption of the company was reduced by 32,647 kWh/year, which corresponds to 36.0% energy saving in water pumping. In addition to these tangible improvements in the environmental performance of the company, working environment was also improved in terms of the health and safety of the workers by reducing evaporation of the chemicals and eliminating dripping to the floor. Implementation cost of the applications were $34,233 which is calculated to be paid back in 2.3 years.

Chemical Industry (Company D). Before this study, Company D consumed 181,921 m^3/month of water as process water and cooling water. Water was also used for other activities at lower amounts, such as cleaning and other domestic purposes (4.1% of total consumption). Groundwater is the only water source of the company and is used without any pretreatment, primarily for cooling of equipment in almost all of the processes. This comprised 61.4% of total water consumption. On the other hand, groundwater is pretreated via an ion exchange system to be used as soft water in all of the processes as process water. Soft water is also used for cooling of heat transfer systems, which contain heat transfer oils at 300–350°C. In this operation, 27,025 m^3/month (8.1%) of soft water was used instead of groundwater in order to prevent scaling in the heat transfer pumps. Thus, 70.8% of the water consumption of the company is due to cooling needs in various processes.

European Commission (2007) states that it is possible to produce 1 ton of Polyethylene Terephthalate (PET) through Dimethyl Terephthalate (DMT) process by consuming 0.1–2.2 m^3 of water. Before this study, the company consumed 7.3 m^3 of water for one ton of polyethylene terephthalate (PET) produced with DMT process. This finding is regarded as the first evidence that significant water savings is possible in the company. Supporting this claim, the specific cooling water consumption of the company (5.6 m^3/ton) was higher than the reported values in the literature for producing various polyesters (0.5–2.5 m^3/ton) (European Commission, 2007). Since cooling is by far the highest water consuming activity of the company, this fact also explains the excessive total water consumption.

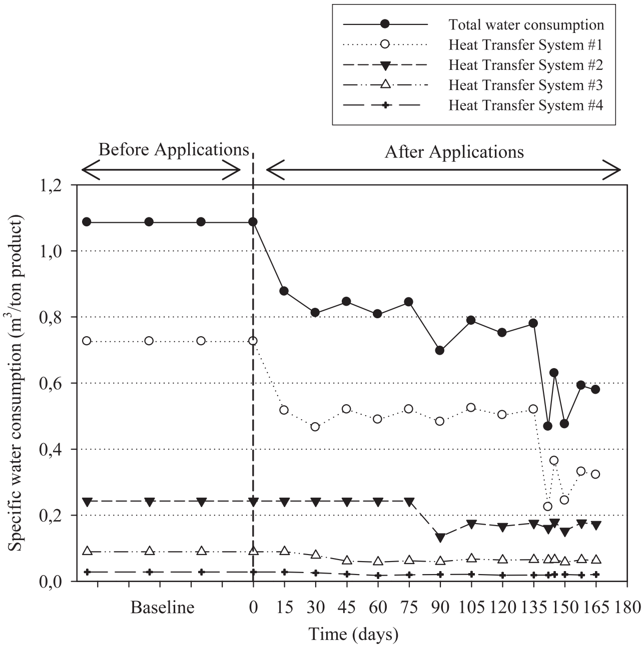

Figure 3—Specific soft cooling water consumption in heat transfer systems before and after applications in Company D (Chemical Industry).

It is also stated in the literature that water cooling should be reconsidered where air can be used as an alternative cooling medium in the cooling systems (Environment Agency et al., 2003; European Commission, 2001). According to CIRAS (2005), the amount of equipment that cooled by water must be reduced in chemical industry by using more advanced and less heat sensitive materials. There are commercially available heat transfer pumps which rely on air stream for cooling purposes and do not require any water (Arneth and Dötsch, 2006; Werner, 2006). Based on these discussions, six different types of soft water-cooled heat transfer pumps (11 of total 19 pumps) were replaced with air-cooled pumps in order to reduce soft cooling water consumption in heat transfer systems. Installed pumps are horizontal volute centrifugal pumps and operate as single-flow and single-stage with optimized bearing support consisting of housing cover, including throttle/cooling section and bearing support (Arneth and Dötsch, 2006; Werner, 2006).

Since the major objective of the substitution of heat transfer pumps was to decrease the water consumption of the company, soft cooling water consumption was monitored for 165 days (Figure 3). As a result of elimination of cooling water use in 11 of 19 pumps, soft cooling water consumption was reduced in each of the four heat transfer systems. Through this application, the total specific soft cooling water consumption in heat transfer systems was reduced 46.7% from 1.09 to 0.58 m^3/ton product manufactured. Thus, the total soft water consumption of the company was decreased from 62,783 to 50,164 m^3/month (20.1%). Total annual cost saving was calculated to be $104,905/year. Total cost of installed air-cooled heat transfer pumps (11 pumps) were $50,082. So, the payback period of the investment was approximately six months.

Textile Industry (Company E). Sustainable production measures which were taken in various processes of Company E resulted in reductions of soft water consumption in production processes, cooling processes, and utility operations. The highest water saving in terms of total monthly water consumption was observed in wet production processes, namely fabric preparation, dyeing and finishing. Water consumption was decreased from 16,940 to 8,925 m^3/month as a result of the shift from overflow washing/rinsing to drop-fill method (European Commission, 2003). Consequently, specific water consumption in wet production processes was reduced from 84.8 to 40.9 L/kg fabric, corresponding to a percent decrease of 51.8%. On the other hand, the highest percent decrease of specific water consumption was determined in water softening system. Reduction of water consumption by 86.9% is associated with both the renovation of ion-exchange system and the decrease in soft water demand as a result of all sustainable production measures taken in the company. Although steam generation was not targeted in any of the sustainable production applications, the reduction of water consumption in production processes led to a decrease in the need for steam which is mainly used for increasing the temperature of water baths in the company. Therefore, 37.8% decrease was recorded in terms of specific water consumption in steam generation.

Monthly average specific wastewater generation was decreased from 124.1 to 70.2 L/kg fabric, which corresponds to a decrease of 43.4 % (Figure 4). The percent decrease in the specific wastewater generation (43.4 %) was very close to the percent decrease in total specific water consumption of the company (40.2%). These results are also in line with the statements in the related literature. For example, according to NCDENR (2009c), wastewater reductions as high as 70% are possible if careful auditing and implementation of sustainable production measures are ensured.

Since water consumption was reduced considerably, the concentration of chemical oxygen demand (COD) and electrical conductivity were increased by 33.1% and 29.6%, respectively. However, if the specific values are taken into consideration, the organic load was decreased 25.5%. This decrease in organic load could not directly be associated with sustainable production applications, since the use of organic chemicals/auxiliaries was not targeted in this study. Still, the decrease in water consumption could have triggered the increased efficiency in chemical/auxiliary use. On the other hand, one of the other important results of this study is the 26.1 % decrease in the load of specific electrical conductivity. Since salt (NaCl) consumption was decreased substantially, electrical conductivity was decreased accordingly.

Since natural gas is primarily consumed for heating the water baths, the reduced water consumption decreased the energy consumption as well. Accordingly, total energy consumption of the company was decreased by 17.1% while direct CO_2 emissions, which are directly related to natural gas consumption, decreased by 20.2%. Renovation of ion-exchange system and decrease in soft water demand as a result of all sustainable production applications decreased the amount of salt (NaCl) consumption for the regeneration of ion exchange system. So, the total salt (NaCl) consumption of the company was decreased by 46.0%. The payback period of the implementations was calculated as around 1.5 months.

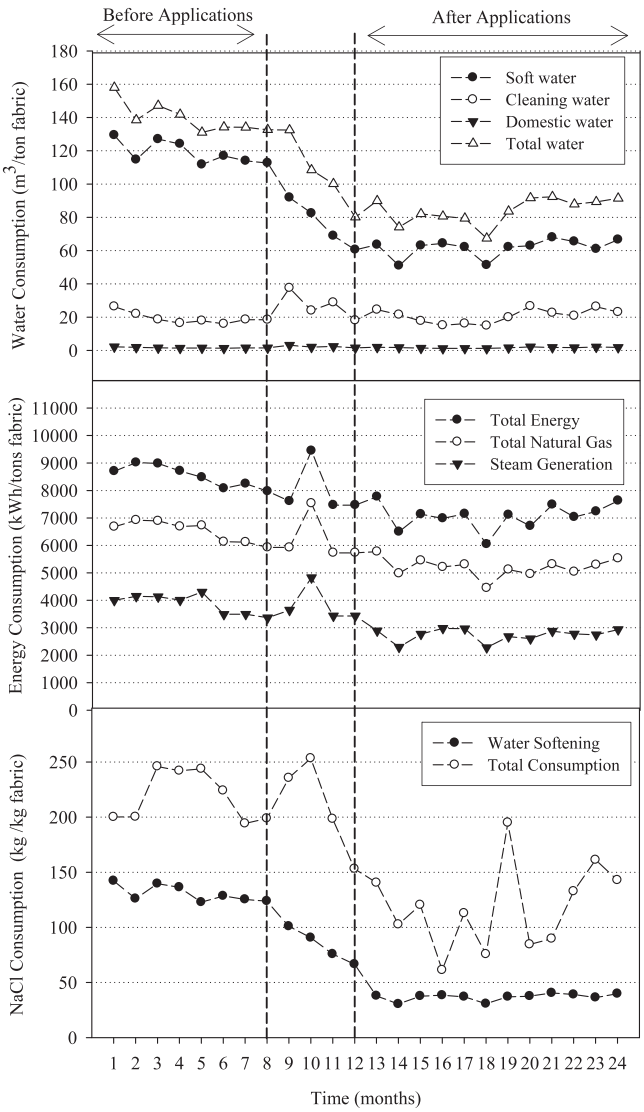

Figure 4—Change of specific water, energy and salt (NaCl) consumption as a result of applications in Company E (Textile Industry).

Surface Coating/Painting Industry (Company F). As an outcome of the Environmental Performance Evaluation of Company F, solvent based degreasing (hand wiping) was found to be the main factor of important environmental and health effects as well as high operational costs. Envirowise (2003) states that replacement of hand-wiping processes with an automatic, fully enclosed, aqueous degreasing process yielded improved environmental performance in a company where organic solvents were in use. Moreover, replacing organic solvent degreasing (hand wiping) process with combined aqueous degreasing and surface coating enabled two different companies to save labor costs and decrease VOC emissions (Envirowise, 2003). Based on this information, hand wiping process was replaced with an aqueous degreasing process in Company F.

As a result of this change, degreasing solvent consumption (637 kg/month) was totally eliminated. Instead, the company started to use 45 kg/month of an aqueous alkaline degreasing chemical. In other words the degreasing chemical consumption

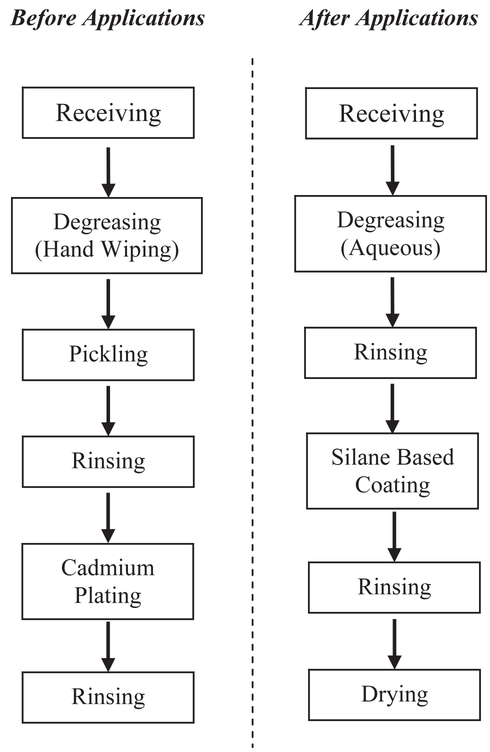

Figure 5—Coating process flow diagram before and after applications in Company F (Surface Coating/Painting Industry).

of the company was reduced by 92.9% by weight. Before this application, 764 man-hours were used monthly for the hand wiping of work pieces in solvent degreasing process. The required workforce was also reduced by 60.7% and became 300 man-hour/month. This achievement is mainly due to degreasing of several work pieces at once by dipping into the degreasing vat in a drum instead of processing one by one. As a result of this implementation, a total cost savings of $30,649/year was secured, while the working conditions of workers was improved due to the elimination of a major VOC source in the company.

Environmental performance evaluation also indicated that cadmium plating line, relying primarily on the use of cadmium oxide (CdO) and sodium cyanide (NaCN), is the major source of hazardous waste generation in the company. Among the environmentally benign alternative coating/plating processes, silane based coating is at the forefront of emerging technology that offers high corrosion resistance and stable adhesion to a broad range of paints (Materne et al., 2006; Hu et al., 2007; Li et al., 2010; Jiang, Wu, Hu, Zhang, and Cao, 2012). Accordingly, the cadmium plating line was replaced with organosilane coating line in order to eliminate cadmium and cyanide consumption in the company (Figure 5). Implemented coating process composed of three consecutive operations: (i) silane based coating, (ii) rinsing, and (iii) drying.

As a result of this change, cadmium oxide (CdO) and sodium cyanide (NaCN) were removed from the operation of the company. Thus, 103 kg/month of CdO was saved while NaCN savings were at a rate of 435 kg/month. Instead of consuming 538 kg/month of hazardous chemicals, it was possible to attain required corrosion resistance prior to the topcoat paints by using 6.3 kg/month organosilane polymer. In other words,

Table 3—Environmental and economic gains achieved in the companies as a result of applications.

Companies	Water saving (m^3/year)	Natural gas saving (MWh/year)	Electricity saving (MWh/year)	Total energy saving (MWh/year)	CO_2 reduction (tons/year)	Chemical saving (tons/year)	Other gains
Company A	29,002	-	15.2	15.2	9.0	-	improved product quality generation of valuable by-product
Company B	503,893	-	-	-	-	-	resolved issues in wastewater treatment plant
Company C	18,831	-	32.6	32.6	19.2	1.4	reduced amount of wastewater treatment sludge reduced VOC emissions improved health and safety conditions
Company D	151,428	-	117.8	117.8	69.5	-	reduced auxilary cost reduced maintenance requirements
Company E	146,514	3,441	-	3,441	825.6	263.4	ensured compliance with the national regulations
Company F	-	-	-	-	-	13.6	ensured compliance with the EU regulations reduced workforce and production time
Total	849,668	3,441	165.6	3,607	904.1	278.4	

coating chemical consumption was reduced by 98.8 % on weight basis. In total, a monthly cost savings of $1,238 was achieved as a result of the phase out of CdO and NaCN from the process line. Moreover, the phase out of these hazardous chemicals enabled the company to start operating through a European Union (EU)-compliant surface coating process.

The total annual cost savings was calculated to be $43,372/year by multiplying specific cost savings ($82.74/1,000 m^2) with the annual production of 486,000 m^2. The annual cost savings ($43,372/year) was as high as 8.4% of annual turnover ($512,500) of the company. This analysis indicates that improved resource efficiency significantly enhanced the competitiveness of the company. During the implementation of resource efficiency measures, $29,500 was spent on the equipment. So the payback period of the implementations was approximately 8.2 months.

Conclusion

In this study, the main objective was to investigate the resource efficiency and sustainable production opportunities in six companies from different sectors as a way to contribute to their climate change adaptation efforts. "Environmental Performance Evaluation" was carried out in each of the companies in order to determine areas/processes where significant improvement potential is present. As a result of environmental performance evaluation, objectives were set for each company to decrease the negative environmental impacts and production costs associated with the high impact processes/practices. To achieve these objectives, 77 options were developed for six companies. Based on the opportunity assessment, 19 options were selected and implemented in the companies.

Table 4—Implementation costs and payback periods of applications.

Companies	Implementation cost ($)	Annual cost savings ($/year)	Payback period (months)
Company A	76,900	48,175	19.2
Company B	56,960	97,003	7.0
Company C	34,233	14,760	27.8
Company D	50,082	104,905	5.7
Company E	21,936	170,868	1.5
Company F	29,500	43,372	8.2
Total	269,611	479,083	6.8

Since the major aim of the applications was to increase water use efficiency in the companies, significant water savings (849,668 m^3/year) were achieved as a result of applications targeting reduction of water use (Table 3). In addition to water, 3,607 MWh of total energy was saved in the companies by decreasing natural gas and electricity consumption associated with water heating/pumping. Due to energy savings, CO_2 emissions of companies were reduced considerably by 904.1 tons/year. Chemical savings were also achieved by process and technology changes in metal processing, textile, and surface coating/painting companies. In total, 278.4 tons/year of chemicals (e.g., NaCl, CdO, NaCN) were prevented from being used and ending up in the wastewater. By this way, pollutant load in generated wastewaters were decreased substantially. Besides all these tangible improvements, other gains were achieved, such as improved product quality, improved health and safety conditions, reduced maintenance requirements, and ensured compliance with EU regulations (Table 3).

During the implementation of sustainable production measures, $269,611 was spent for the equipment (Table 4). Total annual cost saving was calculated to be $479,083/year. Thus, the payback period of the implementations was approximately 6.8 months.

To the best of the authors' knowledge, this study is the first in Turkey which was devoted to private sector adaptation to climate change. "Sustainable production," which is based on the concept of creating more goods and services while using fewer resources and creating less waste and pollution, is one of the options that Turkish manufacturing industry can apply toward climate change adaptation purposes. This study will be expected to serve as a building block in Turkey for the integration of climate change adaptation and mitigation approaches in industry, since water efficiency (adaptation) and carbon reduction (mitigation) are achieved simultaneously. The results of the study indicate that the widespread uptake of proposed sustainable production measures would generate a tremendous change in the Turkish manufacturing industry even without heavy investments for technology changes. Moreover, the economic returns would help Turkish manufacturing industry to sustain its competitive position in the global markets, which face a pressing challenge of low cost, high quality, and environmentally benign production.

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