Journal of Cleaner Production 17 (2009) 380–390

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Cleaner production in Danish fish processing – experiences, status and possible future strategies

Mikkel Thrane*, Eskild Holm Nielsen, Per Christensen

Department of Development and Planning, Aalborg University, Fibigerstraede 13, 9220 Aalborg Oest, Denmark

A R T I C L E I N F O

Article history:
Available online 24 September 2008

Keywords:
Fish processing
Fish
Environment
Cleaner production (CP)
Environmental management systems (EMS)
Life cycle assessment (LCA)
Water consumption
Wastewater
Energy
Packaging
Transport

A B S T R A C T

Danish fish processing industry has been one of the pioneers regarding implementation of cleaner production and environmental management systems. This article describes the experiences with cleaner production (CP) among leading Danish industries producing pickled herring and canned mackerel. The article emphasizes two case studies of 'first mover' companies, but data from other 'proactive' companies are also included.

The article provides an overview of different types of CP solutions, improvement potentials, synergistic effects and possible trade-offs. The development of the applied solutions from the late 1980s until today are analysed and recommendations to future strategies at company level and policy level are provided. It is concluded that significant environmental improvements have been obtained for the analysed companies – especially concerning reductions in water consumption, wastewater emissions, and utilisation of fish 'waste' for valuable by-products. Still, more focus could be placed on the reduction of energy consumption, change of packaging types, and environmental impacts in other stages of the products life cycle.

Authorities and companies have mainly focused on on-site reductions of wastewater emissions, but life cycle assessments show that more attention should be given to the reductions of environmental impacts in other parts of the product chain, e.g. fishing operations and transport as well.

1. Introduction

In the late 1980s, the Danish Environmental Protection Agency (EPA) required that all fish processing industries should be connected to wastewater treatment plants, except for large plants that were given the possibility of establishing separate treatment and separate discharge of wastewater. Ultimately, the emission limits would be the same as for the public wastewater treatment, but to motivate the introduction of cleaner production, the EPA made it possible to make a gradual change towards compliance. The idea was that the companies should see how far they could get by means of CP solutions, and then add end-of-pipe solutions, if necessary, at a later stage rather than the other way around. Despite the general focus on wastewater treatment in the late 1980s, authorities and companies became convinced that cleaner production (CP) should have first priority in the fish processing industry [1,2].

The EPA's first programme for the promotion of cleaner production was introduced in 1986 and lasted three years, but it was replaced by another between 1990–93 and again from 1993–98 [3]. During this period, at least 15 CP projects were conducted related to fish processing, mainly within the pelagic segment of the fisheries (processing of herring and mackerel). One of the reasons is that the processing of mackerel and herring often results in higher emissions of organic matter – hence, higher levels of biological oxygen demand (BOD) and chemical oxygen demand (COD). This is because these species are gutted on land and because their oil content is high [2]. Recent life cycle assessment (LCA) studies confirm that it is relevant to focus on the processing of herring and mackerel – partly because the environmental impact potential is generally larger compared to the processing of other species, but also because other stages in the life cycle such as harvesting are considered less important [4].

From the mid-1990s, two additional programmes were launched that focused on environmental management systems (EMS) and occupational health and safety. Several fish processing industries benefited from this and the first EMS certifications (EMAS and ISO 14001) in Denmark were actually obtained by fish processing industries [3].

Considering the problems addressed by CP and EMS in the fish processing industry, most attention has so far been given to the on-site improvements, in particular to the reduction of water consumption and wastewater emissions. This has been motivated by

* Corresponding author. Fax: +45 9815 3788.
E-mail address: thrane@plan.aau.dk (M. Thrane).

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doi:10.1016/j.jclepro.2008.08.006

significant water costs and the introduction of gradually more demanding emission limits for wastewater spurred by the lowering of emission limits in the first Action Plan for the Aquatic Environment in 1987 [1–3]. From a public policy perspective, it appears that the Danish strategy has changed from rather technically oriented CP projects, to projects focusing on managerial aspects and continuous improvements, towards life cycle thinking in the new millennium [3]. Hence, the approach has been characterised by:

- Promotion of CP – instead of (or before) end-of-pipe solutions;
- Focus on water input and wastewater output;
- Focus on 'on-site' problems and solutions;
- A shift from technical CP projects to a focus on organisational aspects (e.g. EMS).

A significant amount of literature about the Danish experiences with CP exists especially concerning the options for technical improvements. A key reference is made by Andersen et al. [5] who provide a good overview of best practices of processing demersal fish, shellfish as well as pelagic fish (herring and mackerel). Two important international reports have also been published by the Nordic Council of Ministers and UNEP, respectively, which provide an overview of cleaner production options in different types of fish processing [6,7]. Both reports are partly based on data from Andersen et al. [5]. A study of energy consumption and options for energy improvements in the Danish fish processing industry is also available by Matcon and Dansk Energi Analyse [8].

The Cleaner Technology group at Aalborg University has conducted several investigations in this field as well [9–17]. Members of the group have written the Danish equivalent to the best available technology (BAT) notes on this branch of industry [18].

This article provides an overview of the development in CP solutions in two case companies (Section 3) and the development in environmental indicators for five herring processing companies over a 15-year period (Section 4). A number of studies exists which describes CP solutions in other countries e.g. Refs. [19, 20]. But the present article only addresess the experiences from Denmark.

2. Methodology

2.1. Scope of the study

The first part of the analysis is based on a detailed case study of two environmentally proactive fish processing companies within the pelagic segment namely Saeby Fiske-Industri A/S (case A) and Erik Taabbel Fiskeeksport A/S (case B). The company characteristics are listed in Table 1.

For both companies, the analysis includes the development in CP initiatives, opportunities in focus areas, synergistic effects, possible trade-offs, and the potential for future improvement.

In addition to the detailed case studies (A and B), the article includes a benchmark analysis, of five of the largest herring processing companies in North Jutland, Denmark, of which one is case B. Unfortunately complete datasets were not available at case A because parts of the company burned down in 1998. The four additional companies are kept anonymous and named companies 1, 2, 3, and 4. The benchmark analysis supplements the case studies and provides a basis for generalization. The intention of the 'complete' analysis is to provide an overview of the Danish CP experiences, to pinpoint the most obvious improvement potentials, and to provide recommendations for CP strategies at the company level.

2.2. Data collection

The main data sources of the current study are the company's publicly available green accounts, environmental reports and interviews. Interviews were carried out in the year 2000 as part of a project about innovation in the Danish food industry [13] and again in 2006 as the basis of the present article [23–27].

Additionally, data from environmental approvals, other relevant internal documents and from a previous study of inputs and outputs have also been used [11,14]. The latter covers the inputs and outputs for the period of 1989–97 and is mainly based on internal documents and environmental permits as can be seen in Table 2.

The interviews in year 2000 were undertaken as part of a project financed by the Council of Northern Jutland, which focused on environmental regulation, innovation and quality within the Danish fish processing industry [13]. Apart from the empirical studies, the article draws on experiences from previous studies of the Danish CP programmes in relation to the fish processing industry mainly within the pelagic segment [5,7] but also other references from the Cleaner Technology Group mentioned previously.

Table 1
Company characteristics of cases A [21] and B [22]

	Saeby Fiske-Industri A/S (case A)	Erik Taabbel Fiskeeksport A/S (Case B)
Established	1947	1948
Number of employees	150	90
Locality	Saeby – Northern Jutland	Skagen – Northern Jutland
Main product types	Canned mackerel	Pickled and sour herring in barrels
Other products	Frozen Mackerel	Herring (salted, frozen fillet, matjes fillet, and herring roe)
By-products	Fish meal and oil (produced on the premises) Pet food Fish waste used as fertilizer	Fish oil and fish waste used for production of fish meal and oil
Product volume per year	100–300 million cans a year	Not publicly available
Environmental Management System	Management system based on the principles of ISO 14001 (not certified)	ISO 14001 EMAS II OHSAS 18001
Export markets	Western Europe, US, Hong Kong, and Australia.	Western Europe

2.3. Concepts and definitions

The term 'cleaner production' has many connotations. The present article applies the definition adopted by UNEP, which describes cleaner production as:

> "...the continuous application of an integrated preventive environmental strategy to processes, products, and services to increase overall efficiency, and reduce risks to humans and the environment." [26].

Hence, CP is a preventive strategy which may address both manufacturing processes and products and which interprets the development of cleaner products as the most radical type of

Table 2
Overview of data sources applied in the current study

	Case A	Case B	Company 1	Company 2	Company 3	Company 4
Interviews in 2000 [13]	x	x	x		x	x
Interviews in 2006 [23–27]	x	x	x			x
Green accounts [21]	x			x	x	x
Env. Statements [22]		x				
Previous benchmark studies [11,14]		x	x	x	x	x

improvement. According to UNEP [29], it is relevant to distinguish between six types of solutions:

(1) Good housekeeping practice;
(2) Reuse and recycling;
(3) Substitution of hazardous materials and chemicals, etc.;
(4) Process optimisation;
(5) Technology change and innovations;
(6) Development of cleaner products [29].

Increased awareness and good housekeeping practices represent the 'low hanging fruits', because investments are at a minimum. Good housekeeping is a natural first step, while cleaner products will often be the last step because it may involve other components of the product chain. It is therefore fruitful to see the solutions as complementary.

In practice, it is our experience that Danish companies interpret cleaner 'products' as the next step, following cleaner 'production' which is mainly seen as a concept referring to preventive improvements taking place inside the companies 'fence', despite the UNEP definition [13].

2.4. Introduction to fish processing

Fish processing is not an exact term, but may include several processes such as sorting, grading, gutting, de-skinning (peeling if shellfish), filleting, and trimming. For some fish or shellfish products, the processing may include breading and filling as well as boiling, pickling, freezing and smoking and different types of packaging, e.g. canning.

The processing depends on the type of product, and in Denmark it is relevant to distinguish between the processing of demersal fish (mainly codfish and flatfish), the processing of pelagic fish (e.g. herring and mackerel), and the processing of shellfish (e.g. shrimp, prawn, lobster and mussels). The processing of demersal fish is typically relatively simple while pelagic fish are often processed into more refined products, such as pickled herring and canned mackerel, which involve more processing. Another characteristic is that pelagic fish are gutted in the factory, while demersal fish are usually gutted on the sea. Together with high oil/fat content, this contributes to higher pollution levels in the wastewater of pelagic fish processing. Shellfish are processed into many different types of product. One of the characteristics here is that the products are usually boiled – contributing to higher levels of energy consumption. Fig. 1 provides an illustration of the main types of fish processing taking place in Denmark. It should be stressed that some processes are not included in the illustration, such as 'traditionally soured' pickled herring, which is not gutted until after the souring process.

For mackerel, the processes are landing, transport, sorting (scaling, grading), removal of head and tail, gutting, freezing (and storing), de-skinning, boiling, filleting, canning, autoclaving, packaging, and storing. For herring, the processes included are landing, transport, sorting (scaling, grading), removal of head and tail, gutting, de-skinning, filleting, pickling (including souring), canning (glass jar), packaging and dispatch.

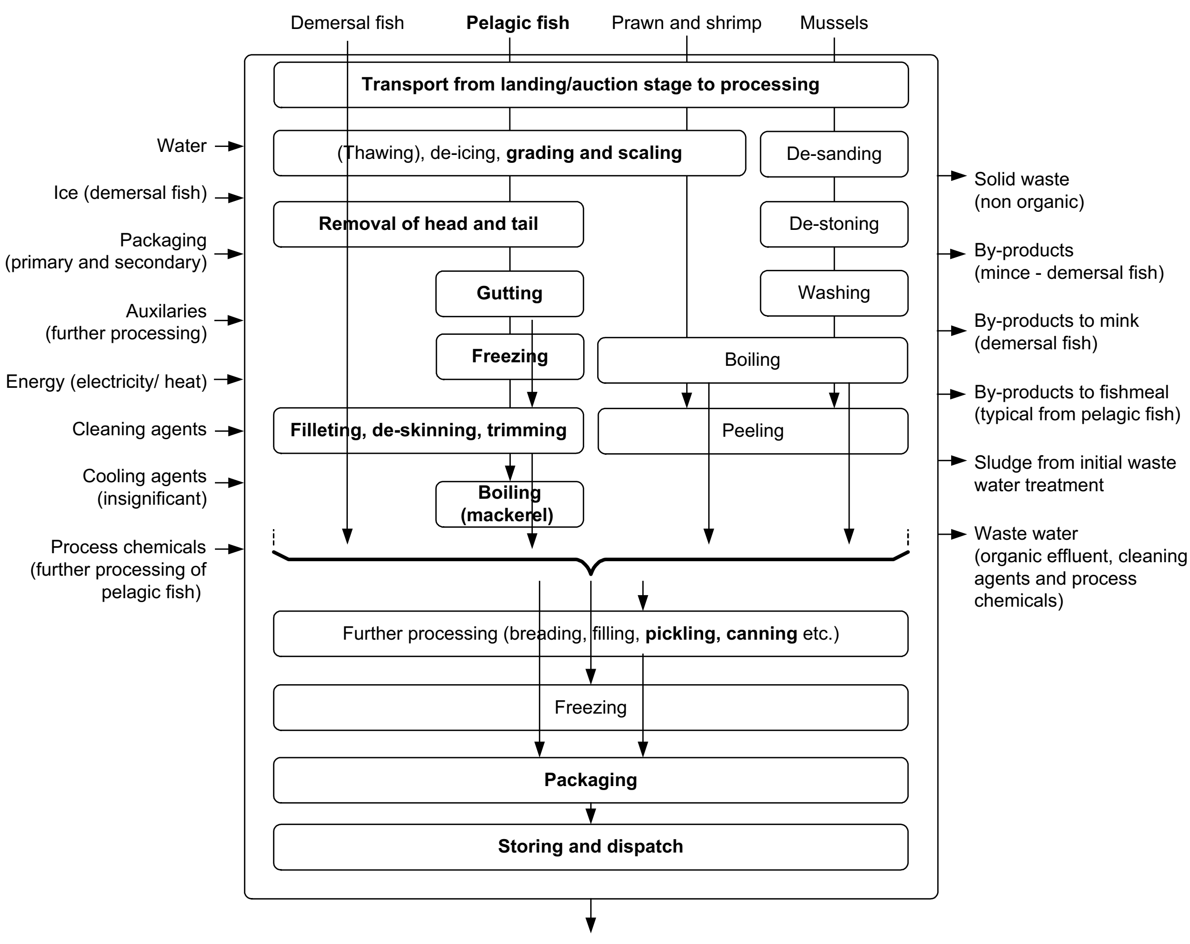

Fig. 1. Different processes and overview of the main categories of inputs and outputs of the four main product categories (or product chains) in the Danish fish processing industry [16]. The product chains investigated in this article are written in bold-faced type.

It should be noted that many inputs and outputs are related to fish processing; but in this article, the focus will be placed on water consumption, wastewater emissions and energy consumption, to the extent that data were available.

3. Analysis of CP initiatives in mackerel and herring processing

The following analysis includes a case study of CP initiatives in the two companies which process canned mackerel (case A) and pickled herring (case B).

3.1. Analysis of case A (processing of canned mackerel)

A/S Saeby Fiske-Industri is situated in Northern Jutland (Denmark) and is the largest producer of canned mackerel in the world with a production capacity of up to 300 million cans per year [23]. The factory processes mackerel, which are received as whole fresh fish and then gutted and de-headed. The fish are then frozen and stored at −32 °C . The fish are taken out continuously as production takes place all year round. The skin is subsequently removed, and the fish are dry-cooked and cooled before entering the filleting process. Further processing steps involve adding brine, canning, autoclaving and storing [21].

3.1.1. Environmental objectives and time line

For decades, the company has been committed to reducing their impact on the environment through preventive solutions. Examples of environmental objectives include:

- Utilise raw materials with a minimum of waste;
- Reduce energy consumption to the lowest levels possible;
- Reduce emissions to the air, water and soil compartments as much as possible;
- Satisfying supplier requirements for certification for genetically modified organism (GMO) free ingredients;
- Environmental requirement by suppliers of inputs such as chemical content and pesticides;
- Environmental consideration in all product development [21].

An overview of the most important CP initiatives is presented in Fig. 2.

3.1.2. Spill prevention, fuel switching and separation of fish oil (1980s)

In 1987, the construction of a new factory began in a new industrial area south of the city Saeby. As part of the design of the production process, environmental aspects were taken into consideration. Environmental initiatives included the optimisation of production equipment to increase the utilisation of the fish [21], the shift from oil to gas as the energy source of all heat-demanding processes (e.g. steam boiling and autoclaving), and the use of cyclones for the separation of fish oil from wastewater [23].

These initiatives must be viewed in the light of a general commitment to continuously develop products and processes, and the total investments were significant. The founder's vision is to be technologically advanced and the factory strives to be emission-free. Despite the fact that the factory was built and equipped in 1987, the plant has more or less been totally redesigned. The different changes of the redesign will be presented in the following. The environmental strategy has been focusing on the aquatic environment (water consumption and wastewater emissions) as well as resource and energy efficiency.

3.1.3. Wastewater treatment and substitution of soda lye with gas (early 1990s)

One of the first initiatives in the 1990s was the introduction of microwave boiling of the frozen fish. This gave a better product quality and reduced the levels of energy – partly due to the microwave oven itself and partly due to the savings on ventilation. However, the microwave technology did not become a success because of the difficulties related to the handling of different sizes of fish at the same time [23].

Another initiative in this period was the establishment of a biological wastewater treatment plant, which could treat all wastewater and thus be allowed as a separate discharge of wastewater. This was not a preventive solution as such, but as a nearby farm was bought and the 'treated' wastewater was used for irrigation, it showed initiative and concern for the environment.

In 1993, the company stopped using soda lye for the de-skinning process. Instead, gas flames were introduced which burned off the skin of the frozen fish. The new type of de-skinning improved the quality of the final products, and made it easier to control the wastewater effluent levels due to the substitution of soda lye. The gas burners only used a small amount of energy – but they did represent a significant fire hazard, as history later showed [23].

3.1.4. Removal of tails earlier in the production

As mentioned earlier, the mackerel are de-headed and gutted before the freezing process. Before the tails were left on the fish during the freezing process. The result was that many tails broke off in the freezing house while others fell off during the processing and ended up in the wastewater stream. A valuable by-product was lost and the tails contributed to higher COD levels. Hence, around 1995, the company decided to cut off the head and tail simultaneously before freezing the fish. The result was reduced COD levels, more waste which could be sold as a valuable by-product, and increased cold storage capacity [23].

3.1.5. Steam instead of water boilers (mid-1990s)

The old water boilers were replaced with new and more efficient steam boilers in 1996, which reduced the water and energy

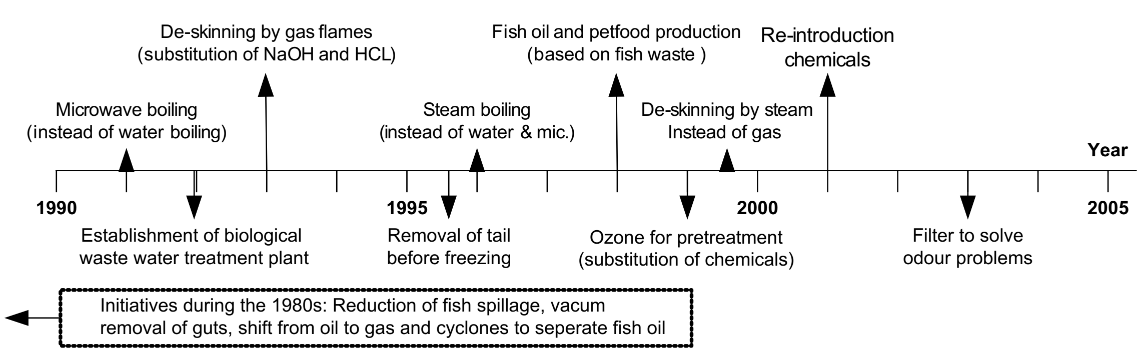

Fig. 2. Examples of the most important CP initiatives at case A from 1990–2005. Based on information available in [21,23].

consumption. Also the quality of canned mackerel and waste products for animal food and fish oil was improved, giving rise to better possibilities of recycling [21].

3.1.6. Fish oil and pet food production (late 1990s)

In the spring of 1997, the company started reconstructing the old flotation plant into a smaller plant in order to get a more simple primary treatment of the wastewater before sending it to the biological treatment plant. The extra space could then be used for producing pet food and fish oil, which were made from leftovers from the canned food production as well as heads and guts. Due to different reasons, the fish oil and pet food plant were not finished until September 1998. It has been both a financial and an ecological challenge for the company to use all waste products in the production of fish oil and animal food [21].

3.1.7. Substitution of polymers (late 1990s)

The company's objective of being totally independent of external handling of sludge from the flotation plant has not yet been fulfilled. This is due to the chemicals in the sludge. The company tried to solve the problem in 1999 by using an ozone system for the pre-treatment of the wastewater, but so far it has not proved to be effective [9].

3.1.8. Switching to steam instead from gas for de-skinning (late 1990s)

As previously indicated the gas-based de-skinning caused a serious fire in 1996. When rebuilding the factory, a new solution was sought that did not involve chemicals or represent a fire hazard. The idea for the second generation of heat solution came when one of the employees watched his wife cooking. He saw how she used boiling water to peel the tomatoes! This led to a kitchen experiment with frozen mackerel which turned out to be successful. The idea was presented to the management which immediately picked up the idea and invested in a new de-skinning technology, based on steam, in 1999/2000. In an interview with the director in 2000, he noted that the solution has many synergies: better product quality, reduced fire hazard and reduced water consumption because significant water quantities previously had been used for cleaning when the gas technology was used.

This example shows how the search for substitution of chemicals may lead to completely new solutions, which also have proven to represent a benefit in terms of better product quality. It also serves to illustrate that different types of solutions (e.g. types 3, 4 and 5) are often used in combination.

3.1.9. Other product-related initiatives (early 2000)

The company has also considered introducing 'organic' products, but currently the problem is that wild fisheries cannot be certified according to the criteria for organic products in Denmark. It is possible, however, that the company will provide fish products with the eco-label from the Marine Stewardship Council (MSC) in the future although this focuses on the state of exploitation of the stocks [23].

A significant impact potential is related to the use of aluminium cans because the production of aluminium requires large amounts of energy [21]. The company has considered other solutions such as plastic (PET), but so far no good alternative has been found, according to the environmental manager [21].

3.1.10. Environmental focus and achievements

Case A has from the mid 1980s been focusing on product and process developments. The philosophy has been to design the processes in a way which secured the optimal utilisation of the mackerel. Most of the mackerel is sold either as canned or frozen mackerel. The rest of the mackerel is used for by-products such as pet food and fish oil. The core strategy has been based on process optimisation as well as technology change and innovations. A future development could be an integration of EMS and more focus on product innovation. So far, Saeby has received relatively few environmental demands from customers.

3.2. Analyses of case B (processing of pickled herring)

The main product of Erik Taabbel Fiskeeksport A/S is pickled herring based on fresh herring that are de-headed, gutted, filleted and pickled. The processing of herring typically results in considerable emissions of wastewater with a high content of organic matter.

3.2.1. Environmental strategies and time line

In the following, the technological and organisational development at case B will be presented. The environmental strategy is a traditional EMS strategy that secures environmental improvements by applying good housekeeping and process optimisation. An overview of the most important CP and management initiatives is presented in Fig. 3.

Experience at case B has shown that the effluent levels can be significantly reduced by applying one of the three simple strategies:

- Separate fish from water to the extent possible;
- Reduce contact time between fish and water;
- Reduce mechanical treatment of fish offal [22].

3.2.2. Separation of fish oil from waste stream (early 1980s)

In the early 1980s, the company took the first initiatives in reducing the contamination of effluent by using centrifugation to separate fish oil from the wastewater. This provided a valuable by-product (fish oil), while significantly reducing effluent levels. This type of solution requires that process water and cleaning water are separated in two distinct systems [13]. This solution is on the border between pollution prevention and pollution abatement, but as it provides valuable by-products (which substitute other types of products) and is applied close to the source of pollution, it has many of the characteristics of prevention and is the first important example of cleaner production at case B.

3.2.3. Focus on spillage and working routines (early 1990s)

The bulk of work with CP began in the early 1990s – mainly by increasing the focus on spillage and working routines. The company director had a strong personal interest in environmental issues and due to the increased attention on the environment among management, employees gradually became motivated to change working routines, especially cleaning, which constituted and still constitutes roughly 40% of the total water consumption [24]. Changed working routines included:

Physical removal of fish waste to the extent possible by use of scrapers and compressed air;
Pre-soaking of floors and processing equipment to increase contact time with cleaning agents;
Reporting and/or adjusting processing or cleaning equipment when malfunctioning;
Reporting on water usage, e.g. after cleaning [24].

Apart from the changes in routines, small investments in technical solutions were necessary as well. These included:

Water pistols that restrict the water flow in the end of water hoses;
Spray nozzles on hoses to ensure more effective cleaning;

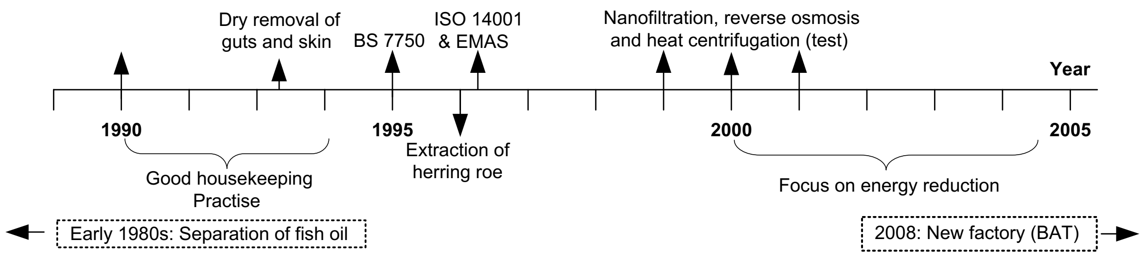

Fig. 3. Examples of the most important CP initiatives at case B in 1990–2005. Based on information available in [22,13,24].

Fitting drains with screens preventing solid materials from entering the effluent stream;
Installation of high pressure water hoses and compressed air;
Installation of water meters [24].

The environmental manager stressed the importance of better housekeeping in this period and characterises it as the overall most important type of cleaner production [24].

3.2.4. Dry transport of fish (early 1990s)

Before the 1990s, large amounts of water were used for transporting fish and fish waste in open drains in the factory floor. The first CP solutions focused on recycling the water, but the limitations of this solution were soon realised. It did not reduce the water consumption significantly nor the emissions of COD, due to the contact between fish and water.

In the early 1990s, the plant personnel realised that dry transport was a better solution. This involved a special type of filter conveyer belts and brushes which transported and positioned the fish in the machines [13,7]. Dry transport is a great benefit for the environment. It saves water, it reduces the content of organic matter in wastewater, and it provides more fish offal that can be sold for fish meal production or pet food [13]. Concerning the latter, it should also be noticed that the fish offal becomes dryer and more valuable because less energy is needed for evaporation during the production of fish meal.

The first conveyer belts were installed around 1990, but the company still uses water for transport in certain processing steps. In 2008, however, a new factory will be built at which conveyer belts will be used under all machines (de-heading, filleting and skinning) – thus entirely avoiding water as a transport medium [24].

Experiments with removal and transport of guts by vacuum have also been conducted, but have not proven successful in the herring industry – mainly due to maintenance problems and noise [24].

3.2.5. Dry removal of guts and skin (early 1990s)

The strong flows of separating fish and water resulted in a number of technological modifications in this period as well. The company's factory engineers modified machines for de-skinning and gutting in such a way that skin and guts were removed and transported to the special conveyor belts without water. This reduced the content of organic matter in the effluent stream even more [24].

3.2.6. Extraction of herring roe and development of machines (mid-1990s)

According to the environmental manager, CP is often a question of solving 'old problems' in new ways, and employee participation and creative thinking are important factors. Creative thinking is also a matter of changing perceptions of 'waste'. At case B, 'waste' is redefined and now seen as a potential 'valuable by-product'. Previously, herring roe was treated as a waste product, but today the roe is gently removed, cleaned and sold on the Japanese market as a luxury product, an example of CP solution type 2 [13].

One of the characteristics of case B is the strong involvement of employees, which has been reflected in the strong focus on good housekeeping practice already from the early 1990s (see Section 3.2.1). The processing equipment has continuously been developed as a result of close co-operation between the company's own factory engineers and the suppliers of processing equipment [24]. One of many examples is the development of machines for the removal of herring roe (herring roe separator) in which the company has been involved in obtaining a patent. Another example is the development of machines for dry gutting and dry de-skinning in the early 1990s [13].

3.2.7. Implementation of environmental management systems (mid-1990s)

As mentioned, management aspects and working routines were included already in the beginning of the 1990s, and the company was actually among the first Danish companies, at all, that obtained a certified environmental management system. The first certification was obtained in 1995 according to the British Standard BS 7750, and in 1996 the company obtained certification according to ISO 14001. In 1996, it obtained an EMAS registration as well. Today the company has included working environment in their management system and has obtained a certification according to OHSAS 18001 [15].

3.2.8. Cutting edge wastewater treatment (late 1990s)

In the late 1990s, experiments were also performed with an advanced type of filtration which involved heat centrifugation, reverse osmosis and nano-filtration. This reduced the effluent levels to almost zero, and had the potential to provide valuable by-products. But in the end, this technology turned out to be costly and unreliable. Another disadvantage was that it required considerable amounts of cleaning agents and energy (electricity). LCA studies showed that the environmental benefits were eroded by the significant energy consumption, which illustrates the limitations of the end-of-pipe approach. The project was stopped after 3 years, but the heat centrifugation remained [13,30].

3.2.9. Energy reductions (2000 -)

After a period with a strong focus on water and wastewater, the focus gradually expanded to include energy consumption from 2000 to 2005. As in the case of water issues, it began with a review of energy use by an external consultant. The CP initiatives implemented in the following period included changed working routines as well as technical modifications.

An example of the change in working routines is the practice of truck drivers, who began to turn off their engines when idle and during lunch and coffee breaks. Another problem related to trucks was the fact that the doors of the factory remained open when trucks entered or left the buildings, thus allowing heated or cooled air to escape. However, it was very difficult to change the routines of the drivers, and the company therefore chose to install automatic doors. Today, automatic double doors are installed in most places [24].

Other examples of technical solutions included the shifting of electric engines and pumps to smaller sizes or more effective types, instead of using engines which are too big for the purpose. Smaller pumps can be used in many cases – especially if the diameter of the pipes is increased – due to the reduction in friction.

3.2.10. Other initiatives

The development in automation means that machines and robots have gradually taken over processes which were previously handled by human labour. So called 'vision equipment' has been installed in recent years. Vision equipment involves a camera and secures the quality of the product. It makes sure that only the correct fish species enter in the process; that the fish are sorted and positioned in the right way, etc. Hence, the need for human labour is being reduced. This may have some negative social impacts, but the Danish Working Environment Authorities are positive because it reduces work-related injuries, especially those related to repetitious and monotonous work. The impact on the external environment is not significantly influenced by the increased automation [24].

3.2.11. Environmental focus and achievements

Case B was among the front runners in implementing an EMS, but customers' environmental demands have been limited. Nevertheless, we consider the company EMS as a success because it provides an organisational framework for CP projects. Workers' participation and change of routines have had a significant environmental benefit and, according to the environmental manager, the payback time is counted in hours. The fact that the company has implemented an EMS sustains the efforts of better housekeeping. Dry transportation of fish and waste as well as better housekeeping have been the key principles for process optimisation. The environmental strategy has had a significant environmental impact both in terms of reduction of COD and water consumptions. A more detailed discussion can be found in our benchmark analysis.

3.3. Overall assessment of tendencies, CP initiatives and opportunities (cases A and B)

3.3.1. Towards a more holistic environmental strategy

Both companies have worked intensively with cleaner production for nearly two decades. The bulk of the work took place in the beginning of the 1990s, and this is also the time when the major improvement has occurred – see the development tendency for case B in Figs. 5 and 6. Case A has been oriented towards technological improvements both in terms of process and products developments, while case B soon realised the need for incorporating the improvement projects into an EMS.

Generally, there has been a shift in focus from water consumption to wastewater emissions and finally energy consumption towards the end of the period. Some initiatives have also been taken in influencing suppliers as part of the environmental management systems [13,24]. Obvious areas for improvement in the future are impacts occurring in other stages of the product's life cycle from sea to table. The fishing stage is one example where improvements can be made in energy consumption, emissions of anti-fouling agents and reductions of over-exploitation of marine resources. Hence, we will probably see an expansion from on-site improvements related to water consumption and wastewater emissions, towards reductions in inputs and outputs more generally in the entire life cycle of the products in the future.

3.3.2. Reduction of spillage and its importance

Another important result is that the spillage of fish has gradually been reduced. The fillet yield has only improved slightly through the optimisation of processing equipment, better sorting, etc., but the utilisation of other parts of the fish has increased significantly. I other words, less fish has been transformed into COD in the effluent stream and more has been taken out as valuable by-products. The by-products include:

- Fish oil (extracted via centrifugation);
- Fish meal and pet food (e.g. from filter conveyor and dry removal of skin and guts – case A even has its own pet food production plant);
- Herring roe (from roe separator in case B).

These developments provide additional income and, at the same time, they represent a significant environmental improvement. This improvement is based on the fact that the by-products substitute for other food products, and consequently all the upstream processes related to these products. According to Dalgaard et al. [31], fish oil is most likely to substitute for palm oil (a marginal edible oil), while fish offal can be used for pet food and fish meal can probably substitute for soy meal (a marginal protein source).

Herring roe may substitute for other luxury food products, but this has not been investigated further. Still, the important conclusion is that a large number of upstream processes are avoided. In the case of soy protein and palm oil, this includes land conversion and ultimately contribution to clear cutting of rain forest [31]. Hence, it is clear that the overall environmental impact potential of the two fish processing plants could have a positive effect on several impact categories.

3.3.3. Synergistic effects

Cleaner production projects which address water conservation and water pollution often have synergistic effects. First, a reduction of the water use results in less wastewater. This provides the basis for economic savings and reductions of environmental impacts related to groundwater extraction and wastewater emissions. Another important point is the fact that wastewater treatment plants in Denmark are regulated through emission limits in the form of maximum emission 'concentration' levels rather than absolute emissions of N, P, COD, etc. Hence, a reduction of the water consumption at the processing plant actually reduces the total emissions of N, P and COD from the wastewater treatment plants, as their concentration levels remain fixed due to regulations [4]. This was confirmed by the local wastewater treatment plant that treats wastewater for most of the companies in the present study. They even argue that COD from the processing industries is a small problem and that it boosts the biological processes at the wastewater treatment plant [25].

Less water use obtained through dry transport of fish and less contact between fish and water may also give smaller COD emissions from the factory as well as reduced fish waste (or higher fillet yield).

Finally, it is also likely that the consumption of energy and certain chemicals and auxiliaries can be reduced. Less water consumption simply means less water to be pumped and heated (e.g. for cleaning and washing operations).

Hence, by addressing one environmental aspect, a number of synergies can be obtained in relation to other impacts as well as the economic bottom line (Fig. 4).

Apart from the synergy between environment and short-term economic goals, cleaner production may contribute positively to the companies' image and to the competitive advantage on markets with increasing demands for greener products. Furthermore, advantages can be obtained in relation to occupational health and safety as well. As an example, the increased insulation of the production place in fish processing industries reduces the energy bill, the air emissions, as well as the employees' exposure to draught and cold.

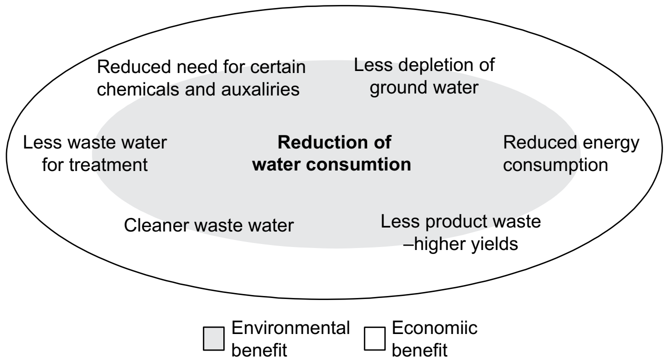

Fig. 4. Environmental and economic benefits related to reductions in water consumption.

3.3.4. Trade-offs

It should be acknowledged that CP does not always result in *positive* synergistic effects. One example is the use of water-saving nozzles for cleaning which in some cases are considered to cause respiratory problems of employees [13].

The two case studies also show that certain technological solutions which are immature may cause more problems than they solve. Two good examples are wastewater treatment by nano-filtration and gas-based de-skinning. For nano-filtration, the environmental benefits were eroded by the increase in energy consumption, while the gas-based de-skinning technology resulted in a fire.

4. Benchmark analyses

Due to our continuous research effort in the last decade, we can describe the improved environmental performances of 5 herring industries (case B and companies 1–4). Based on in-depth knowledge of each company, we are also able to explain the reason for general improvements that can be observed – hence, linking key indicators to developments in CP and EMS efforts within the groups of companies.

4.1. Developments in COD emissions

Based on data collected in this study, the water consumptions and COD discharges fell significantly in the period from 1989 to 2005 as can be seen in Figs. 5 and 6. Meanwhile, the fish processing facilities have increased their product refinement. Most of the companies have changed from discharging directly into the sea to being connected to the municipal sewer system. In 2005, only one of the companies in the study still had separate discharge directly into the sea.

During the 1980s, the fish processing industry was characterised by a large consumption of water and a significant discharge of organic material. Environment and pollution were hardly on the agenda at that time. However, the Danish government established a national cleaner production programme in 1987. At all five herring processing companies, the water consumption and the organic discharge were significantly reduced in the period that followed (Figs. 5 and 6).

The data for COD emissions for the years 1989 and 1990 are considered to be somewhat uncertain and improvements occurring after 1999 are mainly related to advanced biological wastewater treatment in company 1. The most reliable data for interpretation relate to the period 1991–1999. In this period, COD emissions have on average almost been reduced by a factor 5. Measured in absolute figures, this is equivalent to a reduction of 40,000 PE, from roughly 50,000 PE to 10,000 PE (1 PE is equivalent to 90 kg of COD). This is a remarkable achievement, especially because the companies make more refined products towards the end of the period – a tendency that would suggest an increase in emissions.

The largest reductions in COD levels occur in the beginning of the 1990s and in the mid-1990s. Improvements based on preventive solutions have been almost absent since year 2000. All companies have, in a systematic manner, implemented the dry transportation of fish and offal, which limits the contamination of process water. Dry removal of guts, bones and skin are also practiced by all companies. Finally, all companies have optimised the technology processes to almost the same status. The general tendency is that the improvements in the beginning of the period are obtained through simple process improvements and changes in working routines, but the first filter conveyer belts are also established in the early period.

If we take company 3 as an example, the reductions in the early 1990s were mainly related to the elimination of an inappropriate waste handling system in which wastewater was pumped to a reservoir on the roof and led to a flotation tank. This was obviously a bad solution, because the pumping process mixed water and fish waste, which resulted in wastewater with a very high content of organic matter. The first filter conveyer belts in company 3 were established in 1990, but filter conveyer belts were not applied more widely until 1994/95. This happened at the same time as the company purchased new processing machines and as a result, emissions dropped significantly from 1994 to 1995 [27].

It appears that the absolute variations between the companies have been reduced significantly during the period. The remaining difference in environmental performance after year 2000 is mainly caused by different levels of product refinement, different application of abatement technologies and the implementation of different types of production planning [11].

4.2. Developments in water consumption

The relative water consumption also shows a decreasing tendency throughout the period – see Fig. 6. The average water consumption per ton raw material is reduced with a factor of 2–3 towards the end of the period, but as for COD emissions, it appears that most of the improvements happened before 1998.

Most of the improvements obtained in the beginning of the period is the result of better housekeeping practices mainly related to more efficient cleaning procedures. Large reductions can be obtained by making the cleaning staff aware of their consumption, e.g. by encouraging them to register their water consumption after each day. This only requires an investment in a few water meters, a piece of paper and a pencil. The environmental manager at case B stressed that the payback time of such investments was very short and the company had saved around 120,000 Euro in one year through reductions in water consumption due to changed working routines. That was in the beginning of the 1990s. However, today cleaning is often managed by contractors. Hence, the challenge is to motivate the contractors to make water savings. Company 1 required the cleaning company to use less than 50 m^3 per day. This could be done without any reduction in cleaning quality and it halved the water consumption for this purpose [5]. Hence, better housekeeping practices probably play a greater role for water savings compared to COD emissions where process optimisation is more pivotal.

All case companies have reduced water consumption at all stages of the production process by collection of waste in dry state, implementing mechanical herring transport instead of water-borne, reducing water use on the machines, improving the cleaning methods with water nozzles, etc. [13,23,24,27,28].

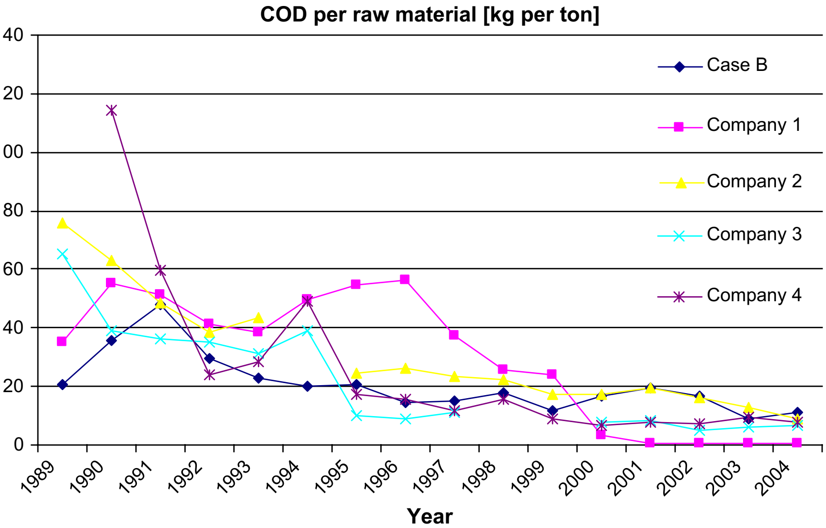

Fig. 5. COD emissions per ton raw material at five herring processing industries [11,14,21,22].

Except for one company, all the companies introduced EMS in the mid-1990s. EMS was by the companies considered to be the next step following cleaner production. It implied that the cleaner production projects were integrated in an organisational framework and that all industries had employed environmental staff and in some cases also an environmental manager. Today, all four companies are still certified according to ISO 14001 and case B is even registered according to EMAS as well [13,24].

4.3. Development in energy consumption

Data for energy consumption have only been available in short periods for the companies in the present study. Interviews revealed that smaller energy reductions have been obtained in several of the companies, but our indicators do not reveal any significant reductions over the period.

However, the companies mentioned several initiatives over the past 5–10 years. At case B, it was mentioned that energy has been an important issue and improvements include smaller pumps, more efficient air compressors, automatic door openers, reduced idling of production equipment and trucks, etc. Despite the efficiency improvements, reductions do not occur because an increased product refinement has also taken place. Automation has increased and a general tendency exists to include more freezing capacity on the company's premises instead of using external suppliers. One of the companies (case A) has actually increased the freezing capacity to the extent that it has started to store food products from other companies in recent years [23].

It is also worth stressing that the source of energy must be considered. As described in Section 3, company A changed from oil to natural gas as a source of heat supply. The improvement in terms of the contribution to global warming, acidification and nutrient enrichment is significantly increased by switching from oil to gas. Indicators for energy consumption are, therefore, more complex and require the use of LCA.

4.4. The role of CP and EMS

Recent figures on pollution level obtained from the herring industry show that a general pollution reduction factor of 5 has now been reached mainly by introducing and employing several different, relatively simple, types of CP and systematising this by

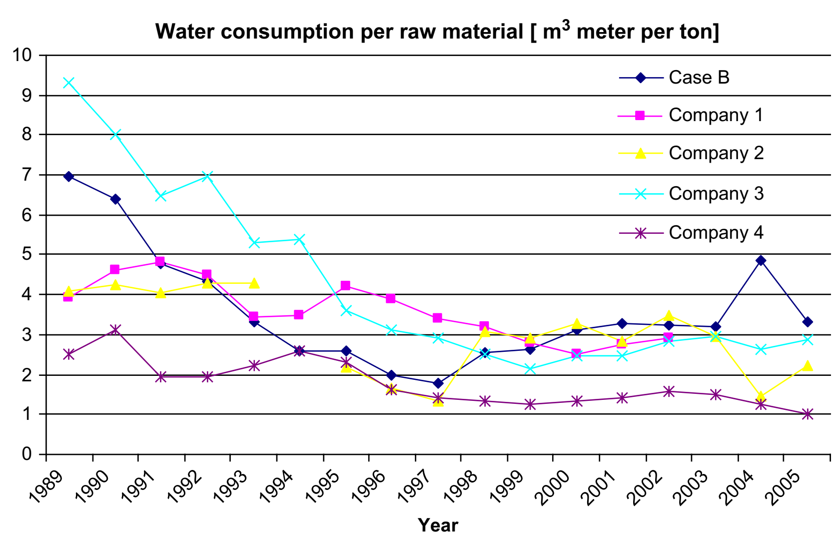

Fig. 6. Water consumption per ton raw material at five herring processing industries [11,14,21,22].

applying environmental management systems. This is in itself very positive, but is strengthened by the fact that the industry in general has refined its products further.

Though the results of the implementation of preventive environmental measures like CP and EMS in the herring industry are quite positive and to the benefit of the general environment, it is evident that CP and EMS should not be applied singularly but simultaneously. In a Danish context, the pollution level is still quite high in untreated wastewater. Hence, the wastewater has to be treated on a wastewater treatment plant anyway.

4.5. Environmental governance and cleaner production

It is important to stress that the cleaner productions practiced by the leading Danish fish processing companies hardly appear by themselves. From a governance perspective, it has been pivotal that new emission limits have been introduced gradually, providing the companies with an opportunity to adapt to stricter emission limits through preventive solutions. This type of self-regulation has also been promoted through green taxes on water and energy as well as subsidies to preventive technological solutions and environmental management systems that create the basis for continuous improvements.

The regulatory focus has, to a great extent, been COD emissions so far, but LCA studies have shown that more concern should be given to energy consumption and environmental aspects related to the fishing stage, packaging, and transport [4,12].

The applied cleaner production projects in the case companies are in line with the recommendation laid down in the EU BAT note on Food, Drink and Milk. More information on BAT can be found at the European IPPC bureau in Seville (http://eippcb.jrc.es/).

5. Conclusions

This article documents how significant environmental improvements can be obtained through cleaner production and simple solutions that require small investments. Environmental indicators for water consumption and COD emissions over a period of 15 years have been analysed. The indicators show that reductions of factors 3 and 5, respectively, can be obtained through continuous improvements and incremental improvements. Good housekeeping practices are important, but process optimisation and reuse have also been part of the solution portfolio. The achieved environmental improvements in the herring industries are beyond the expectations which the consultants had to the cleaner production projects. The explanation is that the companies have implemented management systems, employee participation, and used prevention principles when establishing new production units or introducing changes to the existing productions.

Innovations of a more radical character have also occurred. For mackerel processing this includes vacuum removal of guts, microwave boiling, and de-skinning by gas and recently by steam. For herring processing, it involves the development of machines for removal of herring roe, but there have also been projects focusing on the reuse of the brine used for pickling as well as tests of advanced wastewater treatment by heat centrifugation, nanofiltration, and reverse osmosis.

The case studies indicate that environmental management systems and employee participation are important factors, both for housekeeping practices, innovations, and for keeping the momentum for improvements.

5.1. Lessons learned at the company level

The general conclusion based on our interviews is that better housekeeping practices play an important role for reductions of water consumption especially in relation to cleaning. Due to the relatively high prices on clean groundwater and the low investment costs of good housekeeping, this type of solution had a very short payback time in a Danish context. Reductions of water consumption can also be obtained through the reuse of cleaning and process water, and by different types of process optimisation. The latter includes dry transport of fish offal and better dosage of water in processing equipment. A reduction of water consumption is pivotal because a number of synergies are obtained in relation to energy consumption, COD emissions and better utilisation of the fish (less fish end up in the effluent stream).

Reductions in COD emissions depend to a higher degree on investments in technologies that allow the transport of fish offal and the separation of fish and offal at the earliest stage possible in production.

5.1.1. Broadening the environmental focus

The study unveils a broadening of the environmental focus *to include* water consumption, COD emissions, and energy consumption as the key aspects. All three aspects are important areas of improvement. If effective wastewater treatment is established, it may not be important to reduce COD levels to avoid nutrient enrichment of the recipient, but COD is a good indicator for product loss, and therefore an important optimisation parameter both environmentally and economically. From an environmental point of view, the reduction of product loss is important because it means that less fish has to be caught, landed, transported, cooled, and stored per kg product sold and consumed. A higher production of by-products such as fish meal, fish oil and pet food also substitute for other oil and protein sources which otherwise would cause significant land use impacts in other parts of the world.

5.1.2. Potential for future improvements

Obvious areas for future improvement within processing of herring and mackerel are packaging. LCA studies of canned mackerel and pickled herring show that the impact potential related to packaging makes up a significant part of the total environmental burden [16]. As an example, it would be possible to substitute aluminium cans with PET containers or some kind of pouch of plastic or aluminium with a much smaller material content. Also, it would be possible to put environmental information on the packaging, e.g. about the importance of reducing food waste or the importance of packaging recycling.

So far, the CP initiatives have mainly been addressing on-site aspects – the immediate inputs and outputs on the premises. There are still potentials for on-site improvements, but the most obvious areas for further improvement (seen from an environmental perspective) are hidden in other stages of the products' life cycle. The companies can address other stages (upstream) indirectly by increasing the utilisation factor, but they can also address it directly by influencing the suppliers of fish, ancillaries and suppliers of other products or services, e.g. transport, packaging, vinegar, sugar, salt, vegetable oil, or tomato paste.

Another opportunity is to use eco-labelling such as the Marine Stewardship Council (MSC) which ensures that the fish comes from sustainable stocks see Thrane, Ziegler, and Sonesson in the current issue [32]. Eco-labelled products is one of the measures which can ensure that environmental initiatives are actually communicated to consumers – providing the basis for market feedback in terms of higher sales or prices. The latter has often been lacking – despite investments in CP and certified environmental management systems.

5.2. Lessons learned for public policy

Cleaner production is a question of finding preventive solutions, but it is also a matter of achieving as much as possible by pollution prevention before investing in expensive abatement solutions. The companies, analysed in the present study, have been very successful in doing exactly that. However, this pollution prevention does not occur automatically. The active involvement of authorities and a dynamic approach towards environmental regulation play a great role. By dynamic, we mean that environmental demands (e.g. emission limits) must be tightened gradually (not instantly). Simultaneously, subsidies have been given to promote CP initiatives, while green taxes have created the foundation for synergy between environmental and economic improvements.

For front-runner companies, it is clear that the next step will be in cleaner products in which environmental improvements will be obtained at several stages of the products' life cycle. In the case of Denmark, it was incidents with oxygen depletion in the coastal waters that spurred the strong attention towards COD emissions in the 1980s. This gave rise to the first action plan for the aquatic environment with new emission limits – and the promotion of cleaner production in which companies should make the most of the investments according to the "polluter pays principle". Later, environmental management systems gained momentum and contributed to an expansion of the scope to energy, OH&S and other environmental issues. In this era, companies realised another version of 3P: "pollution prevention pays".

Today, the scope is challenged even more. The World Business Council for Sustainable Development talks about people, planet and profit; yet another version of 3P which embraces the concept of sustainability while referring to life cycle thinking. However, Danish authorities today, do little to encourage companies to take initiatives in this direction (contrary to the promotion of CP during the 1990s). Environmental instruments could include the promotion of eco-labels for seafood products, stricter regulation on packaging, subsidies, new partnerships, product information, etc. Implementing a product-oriented policy requires new regulatory regimes, better collaboration among the stakeholders and more ambitious strategies among the industries as well.

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