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Comparative evaluation of cleaner production working methods

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Cleaner production (CP) working methods should facilitate the search for feasible CP options and contribute to their on-going implementation in a company. Over the past decade, numerous working methods have been developed in order to cater for specific segments of industry. This paper describes, compares and analyses the core components of six Dutch working methods to develop a framework for CP methodologies, to draft guidelines for the selection of an appropriate working method for a certain industry, and to identify areas which require additional methodology development. A division is proposed between four types of CP working methods: indicators, scan, pre-assessment and assessment. Each of these has its strengths and weaknesses, which calls for a careful selection of the working method, which in turn could be based on size of the company, material- and energy-intensity of the production, and complexity of the production processes. This comparative evaluation further proves that the working methods are still weak in stimulating the corporate transition process from 'end-of-pipe' to CP thinking and acting. It is tentatively concluded that an 'assessment' is superior in identifying comparatively radical environmental improvements ('innovations') as well as in fostering the integration of CP into the daily operation and management of a company. The use of simplified working methods in selected industries, is, however, justified given their ability to contribute to the implementation of relatively obvious CP options.

Keywords: cleaner production; working methods; industry

Introduction

A cleaner production (CP) assessment aims at the systematic identification, evaluation and implementation of CP opportunities. The general CP working methods developed during the 1980s have proven to be successful in large-scale (processing) industries. Although these can be applied to small-scale (manufacturing) industries, their application is hampered by the need to scale down and tailor the working method to the company characteristics, which most small and medium sized enterprises are not able to do themselves. In order to reduce the necessary efforts from the company as well as the input from outside consultants, several modifications to the generalized working method have been, and are being, developed and tested in the framework of various Dutch CP demonstration projects. This paper describes, compares and evaluates six working methods in order to develop a framework for CP methodologies, to draft guidelines for the selection of an appropriate working method for a certain industry and to identify areas that might need additional methodology development.

Cleaner production assessments

A CP assessment is often characterized as a systematic planned procedure with the objective of identifying ways to reduce or eliminate the generation of waste and emissions¹. Furthermore, an assessment should initiate an on-going CP programme, catalysing the corporate effort in achieving continuous environmental improvements in its operations. A systematic working method for the execution of an assessment normally consists of a 'method', a 'procedure' and 'external guidance and supervision'. The method provides a conceptual framework for the identification of CP options. The procedure organizes the necessary activities and thus fosters the development and implementation of CP opportunities. The external guidance and supervision guides, informs and stimulates the responsible assessment team at the plant level. The working methods used in various CP demonstration projects differ in all three elements. In order to be able to compare working methods, a short discussion of each of them is needed.

Method

As CP focuses on the manufacturing process that causes the waste stream, the central element of the CP method should be to examine and re-evaluate the manufacturing process. This re-evaluation consists of a 'source identification' followed by a 'cause assessment' and 'option generation'. For the source identification, an inventory should be made of the material flows, entering and leaving the company, with the associated costs. This results in a process flow diagram, allowing for the identification of all sources of waste and emission generation. Next is the cause analysis: an investigation into the factors that affect the volume and composition of the waste and emissions generated. A checklist of some five possible waste generation causes is often used to assess all possible causes. These are: product requirements, input material specifications, technology, process execution (operating practices) and waste and emission characteristics². A materials and energy balance is needed for the evaluation of the relative importance of each of the possible waste generation causes. The purpose of the next logical step (option generation) is to create a vision on how to eliminate or control each of the causes of waste and emission generation. Once again, a checklist of generalized 'CP techniques' (or approaches) could be used to develop appropriate CP options. The set of CP techniques should fit to the set of waste generation causes; the generalized techniques often used are therefore: product modification, input material substitution, technology modification, good housekeeping and on-site recycling. Once CP options have been identified, these should be evaluated, like other investment or technical innovation options.

Procedure

The above-described method should be embedded in an organized procedure. Following this procedure should be instrumental in organizing the CP efforts, informing the necessary stakeholders within the company and bringing together those persons who can develop, evaluate and implement the CP opportunities. The use of a four-step procedure, originally developed by the USEPA³, is still widespread although a number of modifications have been incorporated in more recent publications⁴. The original phases were:

1. *planning and organization*: establishing the assessment-organization and setting priorities and goals;
2. *assessment*: detailed study of processes in order to develop CP options;
3. *feasibility analysis*: analysing the feasibility of each option;
4. *implementation*: (preparing for) the implementation of the feasible options and establishing an on-going CP programme.

With a view to minimizing the necessary efforts for

CP, the use of a pre-assessment as a planning tool for the development of the CP activities has become widely accepted, especially for application in the manufacturing industry in Europe⁵.

Guidance and supervision

The role of 'outsiders' in the development of a CP assessment is often neglected. However, most CP demonstration projects conclude that external guidance and supervision provided by either independent consultant/trainers (from consulting firms, technical assistance programmes, etc.) or by internal consultants (for instance, from specialized staff of the corporate headquarters in a multiple-plant companies) proved to be necessary in order to keep the assessment process going. As with other industrial innovations, several modes of supervision are possible. Process-orientated guidance and supervision, in which the supervisor contributes to the development of the problem-solving capabilities of the company, proves to be superior both in terms of results (implemented innovations) and in learning to innovate⁶. The technical approach (the supervisor supplies the company with the options and the company implements these) as well as the programmatic approach (the supervisor supervises the innovation (or assessment) process, while the company develops and implements the solutions) are less effective in terms of contributing to the development of on-going (technical) improvements. In cleaner production auditing, the supervisor should combine the process-orientated approach with the programmatic approach. In his first role, the supervisor teaches the company how to identify and evaluate its waste problems and how to develop opportunities to prevent waste generation. In the second role, the supervisor creates the necessary conditions for the development of the assessment, for instance by planning meetings, writing reports and preparing internal presentations. In order to emphasize both aspects, it is often said that a supervisor of a CP assessment should be both a trainer and consultant to the company assessment team.

Example applications

Since the successful finalization of the Dutch PRISMA project⁷, a number of new CP demonstration projects have been initiated in The Netherlands. Each of them focuses on companies in either a particular geographical area or a particular industrial sector or of a particular size, and tailors the working methods to these target industries. In order to illustrate the differences, six example applications have been selected. This selection is illustrative and covers the most apparent differences.

Example 1: PROGRES

In the framework of PROGRES, technical assistance has been provided to six small and medium sized enterprises from various industrial sectors (such as

electroplating, textile wet processing and foundry) in the Province of Gelderland. Assistance was provided over a period of 15 months. Fifteen months after the finalization of the assistance, an evaluation study was executed in order to evaluate how each of the participating companies had continued its CP efforts⁸.

Procedure. The assessment has been organized in order to apply the principles of 'learning by experience' and 'motivation by results'. In the preparation phase, management commitment was obtained and a capable and motivated project team organized. Next was the pre-assessment, in which process flow charts were compiled and operations evaluated in order to assess the obvious sources and causes of waste generation. A first estimate was made of the costs involved in order to catalyse corporate self-interest in CP. A brainstorming session was held for identification of the obvious CP opportunities. Finally, a number of priorities was set for detailed investigations. Next was a period of detailed investigations. Depending on the outcome of the pre-assessment, assessments (for selected waste streams or wasteful processes) and feasibility studies (for the obvious options) took place, whilst in addition some obviously feasible options (such as good housekeeping) were implemented. The execution of these detailed investigations served as a starting point for the continuation phase, aiming at the development of a preventive environmental management system. The facility-wide implementation of such a system should give rise to a new series of assessments and feasibility studies, thus starting the system of continuous environmental improvement.

Method. During the assessment, CP opportunities were gradually explored. The pre-assessment included a qualitative source and cause evaluation in order to identify the most obvious CP opportunities. This took place in a brainstorming session with participation from at least the general management and the production management. Sometimes, representatives from the shop floor (such as supervisors) and staff departments participated. Additional options were collected from databases and literature. If this initial option generation did not reveal sufficient options, a detailed assessment was started. This included additional data collection for quantification of the source and cause assessment and a review of recent technical developments. This additional information was used for a second brainstorming session in order to generate additional process-integrated options.

Guidance and supervision. Environmental scientists from the University of Amsterdam supervised the assessments in the companies. Some 12 to 15 progress meetings were held. The supervisors focused on the process-orientated approach in order to familiarize the companies with the CP concepts and methodologies and to foster the initiation of on-going CP activities in the company. In addition, the supervisors had to

fulfil a technical role in order to retrieve information from databases, literature and experts about prevention opportunities.

Example 2: PRECARI

In the framework of PRECARI, three multinational companies (chemical and carpet industry) and one academic hospital received technical and organizational assistance. Important criteria for the selection of these companies were the complexity of the waste water discharges and the need for renewal of the waste water discharge permits. Cleaner production assessments took place, whilst, in addition, decision-making was evaluated through interviews with key persons and feedback of the research findings into the business organization⁹.

Procedure. All three participating companies are technology-intensive and possess well equipped staff departments. Consequently, a lot of process monitoring and environmental data were readily available, which enabled the use of the basic procedure:

1. *planning and organization:* organizing the assessment team and target and priority setting based on the available data;
2. *assessment:* derivation of material balances for selected assessment targets and option generation by means of a brainstorming session in the company;
3. *feasibility analysis:* technical, economic and environmental evaluation of each of the options;
4. *implementation:* preparation of the implementation of the feasible options and measuring progress.

The absence of a pre-assessment is remarkable, but was justified by the company's perception that a pre-assessment would not yield any additional improvements.

At the academic hospital, the situation was remarkably different, given the huge diversity in operations and the lack of data regarding materials use and disposal. To foster the introduction of CP, it was therefore decided to conduct four CP assessments in parallel in different units (laboratory, ward, nutrition unit and cleansing services). Pre-assessments were hardly needed to focus each of the CP assessments and to evaluate the applicability of CP options derived from other hospital case studies. Therefore, the PROGRES procedure has been applied separately in the four parallel assessments in the academic hospital.

Method. Different methods have been applied for option generation within PRECARI. In the companies, brainstorming sessions took place at the end of the assessment phase. Brainstorming was initiated by the cause analyses drafted by the consultants. The sessions catalysed the exchange of ideas and knowledge between the members of the assessment teams. Most options were created on the spot, through synthesis of various 'old' ideas from assessment team members. In the

academic hospital, brainstorming sessions were held at the end of the pre-assessment phase. During these sessions, the consultants brought forward options from CP projects in other hospitals, and the assessment teams discussed the opportunities to apply these in their own organization.

Guidance and supervision. A separate supervisory group with representatives from the company management, participating consultants, public water authorities and water advisory board (RIZA) supervised the company projects. Through participation in these groups, the public water authorities learned a lot about the opportunities and constraints for implementation of CP at the company level. The actual assessments took place under supervision of one or two consultants from various consulting firms, who participated in the company assessment teams. Each of the consultants emphasized different aspects in his supervision. Most attention, however, was given to the technical content (contributing to the development of CP options) and safeguarding progress in the assessment team (programmatic role).

In addition to the CP assessment, company decision-making on environmental issues was evaluated by researchers from the Erasmus Centre for Environmental Studies (Rotterdam University). These evaluations revealed key factors in company decision-making about the implementation of CP options, and contributed to drafting recommendations for improving decision-making in favour of CP. These results were used in the implementation phase of the assessment procedure in order to foster the development of on-going CP programmes.

Example 3: PROSA

PROSA has been initiated in order to foster the diffusion of CP and to develop CP examples in the Schelde River Basin. As part of the project, waste and emission prevention plans have been made for ten small and medium sized enterprises from various industry sectors. In addition, a CP manual for small and medium sized companies has been developed¹⁰.

Procedure. The PROSA manual distinguishes six steps in a CP assessment:

1. *planning and organization*: obtaining commitment and establishing an assessment organization;
2. *prevention study*: identification and development of CP opportunities;
3. *feasibility studies*: evaluation of the feasibility of the CP options;
4. *implementation*: (preparing for) implementation of the feasible options;
5. *progress evaluation*: monitoring progress achieved by the implementation of the CP options;
6. *continuation*: diffusion of the results within the company and integration of CP into regular business structures.

Given the focus on small and medium sized enterprises, the 'prevention' study has been based on a pre-assessment.

The ten participating companies received assistance in implementing this procedure, with emphasis on supervision of the 'prevention study' phase. This assistance was organized as follows. During the first company visit, a plant walk-through took place in order to select the priority areas. Additionally, an assessment team was organized and instructed in collecting the necessary information (with the use of special worksheets). The company assessment team then started to collect the process, material and environmental data and provided this to the supervisors. In most companies, additional meetings were necessary to clarify and evaluate the provided data. The supervisors then processed this into a source and cause evaluation and added some well known CP opportunities. This in turn was used as the starting point for a brainstorming session with the company assessment team. At the end of these sessions, the generated options were classified as 'evidently feasible', 'evidently non-feasible' and 'potentially feasible'. Next, the supervisors collected information on the technical, economic and environmental details of each option and elaborated the results into a waste and emission prevention plan, with recommendations for the implementation of feasible CP options. This plan was then presented to the company assessment team. Approximately 1 year after this presentation, the supervisors returned to the company in order to evaluate how much progress had been achieved in implementing the various options.

Method. Within PROSA, the basics of the CP method have been applied, although mainly only in a qualitative way and only for the pre-selected target waste streams or emissions ('priority areas'). The initial plant walk-through was used to focus the 'source identification' to the most evident waste streams and emissions. The limited availability of process information then forced the supervisors to draft a 'cause assessment' with qualitative judgements about the importance of the various factors affecting volume and composition of the target waste streams and emissions. The brainstorming session in the company was the most important tool for 'option generation'. In their efforts to initiate and facilitate the brainstorming, the supervisors introduced some well known CP opportunities at the start of the session. Although illustrative for explaining the CP concept, this might have hampered creative problem-solving by the brainstorming participants.

Guidance and supervision. Environmental scientists from Erasmus University of Rotterdam and the University of Gent supervised the assessments in the companies. During the first part of the assistance to the companies, the supervisors held a 'programmatic'

supervisory role. They provided the company assessment team with instructions (such as recommended priority areas) and tools (such as the worksheets) and tried to safeguard progress in the execution of the assessment. Once the data had been collected by the company, the supervisors gradually moved into a 'technical' supervisory role; they presented some CP opportunities at the start of the brainstorming and elaborated the results of the option generation into a waste and emission prevention plan for the company.

The evaluation showed that the companies have limited implementation to the good-housekeeping options and the readily available input and technology alternatives ('the low hanging fruits'). Little has been done to elaborate opportunities for far-reaching environmental improvements (such as process changes and/or product modifications). A possible explanation of these findings is the lack of 'ownership' by the companies over the assessment results. This in turn might have been caused by the fact that the supervisors ended their assistance in the technical role and by the lack of support to the companies during the preparation of the implementation of the CP options.

Example 4: meat processing industry

In order to encourage industries to implement CP, the provinces of Gelderland and Overijssel initiated a series of industry-specific CP demonstration projects. For the evaluation of the methodologies applied in these projects, the meat processing project will be used as an example. In the course of 1993, CP and energy conservation assessments took place in ten companies from various sub-sectors of the meat processing industry (slaughterhouses and meat products). In addition to the company-specific waste and emission prevention plans, these assessments should enable the identification of the most obvious CP options for the entire industrial sector¹¹.

Procedure. The assessments in the companies have been organized in six steps:

1. *preparation*: obtaining commitment and organizing an assessment team;
2. *pre-assessment*: identification and evaluation of the waste streams and emissions for the selection of the priority areas;
3. *study (or widening) phase*: additional data collection for the assessment of the causes for waste generation;
4. *option generation*: organizing a brainstorming session in the company with the results of the cause assessment as the starting point;
5. *feasibility studies*: analysis of the feasibility of the potentially feasible options;
6. *implementation*: (preparing for) the implementation of the feasible options.

As part of the preparation phase, the consultants conducted a 'quick scan' in some of the participating

companies (see also example 5). Compared to the general procedure this approach has two distinct features. Firstly, the pre-assessment is only used for the selection of the most important environmental issues in the companies ('environmental bottlenecks'). It is not yet used for the identification of the obvious CP options. Secondly, the assessment of the waste generation causes (in the study phase) has been explicitly separated from option generation (option generating phase), while these are traditionally merged in one phase ('assessment').

Method. In this industry-specific project, the basics of the CP method have been applied, although predominantly only at the qualitative level. Owing to the limited availability of process data and the fluctuations in production (especially in the meat products plants), the supervisors had to draft the 'cause assessment' with qualitative judgements about the importance of the various factors affecting volume and composition of the target waste streams and emissions. The brainstorming session in the company was the most important tool for 'option generation'. The industry-specific focus of this project allowed for benchmarking, which enabled the supervisors to develop additional CP options for each of the companies on the basis of comparison of the operating practices with the other companies.

Guidance and supervision. Two firms provided consultants for supervision of the assessments in the companies. These consultants participated in the company assessment teams, and fulfilled a programmatic supervisory role (providing instructions and tools and safeguarding progress) and a technical supervisory role (contributing to the development of CP options). Comparison of the company results reveals that one of the consultant companies has paid significantly more attention to the programmatic role while the other has paid more attention to the technical role. In addition, the latter has been less tight in its application of the CP concept and included several options for improvement of the operating practices for the existing end-of-pipe waste water treatment facilities.

Example 5: quick scan

Several projects seek to develop simple and fast methods for the identification of the most obvious CP options in a company. The application of these methods should reduce the call on human resources, from the company as well as from the consultant (supervisor) and thereby eliminate one of the hurdles when starting a CP project in a company. Given the diversity in quick scans, we limit ourselves to the discussion of the quick scan developed and tested under supervision of the National Environment Centre¹².

Procedure. The execution of the quick scan consists of three steps: first company visit, evaluation and

second company visit. The entire procedure requires 2.5 consultancy days (excluding preparation time) and about 1 day from the production manager of the company. The first company visit is highly structured in order to collect all available information on the environmental aspects of the production. Special questionnaires are used for this purpose. Included is an on-site inspection during which the consultant has to identify the most obvious CP opportunities. At the end of the first visit, the consultant presents his findings in order to find out which CP opportunities seem to be most useful to the company. Next, the consultant analyses the information and the feasibility of the selected options. His short report is sent to the company prior to the second company visit. The purpose of this second visit is to help the company in (planning for) the implementation of the feasible options.

Method. The quick scan is not based on a detailed application of the systematic CP method. The results depend heavily on the practical information and experiences of the consultant, since options are only generated during the on-site review. Although the consultant should be aware of the most obvious options in the respective industry sector, this is a limited basis for option generation. Additionally, the evaluation of the options is limited to the options that seem most practical to the company at first sight. One might expect that this will exclude all options that require major changes.

These methodological limitations should be evaluated against the limited costs. Additionally, one might think about various applications of a quick scan, such as:

1. identification of the most obvious CP options;
2. obtaining management commitment for starting a fully fledged CP assessment
3. selection of the best motivated and most representative participants in an industry-specific demonstration project;
4. strategy development for integration of CP requirements.

Given a certain objective, one has to evaluate whether it might be useful to execute a quick scan or whether another working method might be more beneficial.

Guidance and supervision. The role of the supervisor (or consultant) is predominantly programmatic; the supervisor forces the company to structure all available environmental data, to describe all previous CP activities undertaken and to react to the applicability of CP options that have proved feasible elsewhere. In addition to this, the consultant has a technical role during the on-site review in identifying additional CP opportunities.

Example 6: cleaner production indicators

CP indicators are currently being developed in order to enable estimation of the order of magnitude of the environmental as well as economic advantages a company might get from the implementation of a CP programme. These industry-specific indicators enable the entrepreneur to compare the performance of his company with the performance of a comparable company that has implemented CP. The results of such a comparison should encourage the entrepreneur to strive towards the implementation of CP. Ideally, the indicators should give a quantitative picture; however, given the complexity of the development of such quantitative indicators, at least in the short term, quantitative indicators (such as energy and material consumption and waste generation per unit of production) have to be supplemented with qualitative indicators (checklists with obvious CP opportunities in the respective industry sector)¹³.

Procedure. A division has to be made between the procedure for the development of the CP indicators and the procedure for their application in a particular company. The development procedure has the following steps:

1. *orientation*: categorization of the production processes used and description of the most important input and outputs;
2. *improvement analysis*: inventory of CP options to be derived from the results of CP demonstration projects, bench-marking studies and recent technology developments;
3. *potential estimate*: integration of the CP options into reference approaches for each of the systematized processes, elaborated into reference values (for material and/or energy consumption, waste generation, etc.) and obviously feasible options;
4. *pilot test*: developing and testing questionnaires for comparison of company figures with the CP indicators.

The application of the CP indicators can take place in various settings. Those currently tested are the use of the indicators by consultants and the use by the entrepreneur. In the first application, the consultant visits the company and helps the entrepreneur in completing the questionnaires and evaluating the results of the comparison with the CP indicators. Once the entrepreneur uses the indicators without assistance from outside consultants, the industry association could foster the proper use of the CP indicators by organizing an information meeting (in order to explain the opportunities and constraints of the use of the CP indicators) and an evaluation meeting (in order to learn from the experiences from a number of companies that have applied the CP indicators).

Method. The basics of the CP method are used to develop the CP indicators. Their application lacks any

specific method. One might say that the methodic complexity is reduced prior to approaching the company, which prevents the company from being puzzled by the methodology prior to having a picture of the possible savings from CP. The pilot development of indicator sets for foundries and metal finishing shops has taught that CP indicators supplement the lists of CP options from CP demonstration projects with specific process optimization opportunities.

Guidance and supervision. The supervisor has a very limited role in the application of CP indicators in a company. The remaining role during the application is above all technical (providing details about the CP options used to arrive at the indicator levels). Despite this, there might be a need for specific assistance to the company, once the evaluation has taken place, in order to plan for the further elaboration and implementation of the CP opportunities identified by the indicators.

The above descriptions of the CP working methods used in the various Dutch CP demonstration projects, reveal quite a lot of differences. In order to summarize and compare the working methods, *Table 1* has been developed. As shown in this table, each of the working methods has at least one unique project feature.

Towards classification and synthesis

Several observations can be made when comparing the example CP working methods. First of all, there are rather substantial differences in the objectives of each of the working methods. Next, there proves to be quite a lot of confusion with regard to the terminology used for describing CP working methods. Finally, there is a need for synthesis of the lessons learned with each of the working methods, both in terms of trying to link working methods to different steps in the corporate transition, or learning, process from 'end-of-pipe' to 'cleaner production' thinking and acting, and in terms of trying to match categories of companies with the most appropriate working methods. Each of these observations will be elaborated below in more detail.

Objectives

Classification of the possible objectives might illustrate the differences in the objectives of each of the CP working methods. There are three possible objectives.

1. *Identification of obvious CP opportunities and/or priority areas for CP:* the working method is primarily used to generate interest in CP from the entrepreneur. In order to convince the entrepreneur of the usefulness of CP for his company, the working method should enable the rapid identification of the most obvious CP options and/or enable the entrepreneur to quantify the possible benefits from the application of CP.
2. *Development of a CP plan:* the working method is

primarily used to prepare a comprehensive set of CP options for (part of) a company and, if possible, to contribute to the (planning of the) implementation of the feasible CP options. The working method facilitates the implementation of CP since it provides the entrepreneur with a set of 'ready-to-implement' solutions.

3. *Initiation of continuous environmental improvement:* the working method primarily tries to contribute to the continuous application of CP to the business activities. Enabling self-activity from company representatives and developing problem-solving capabilities are important aspects when striving for this long-term CP objective.

The three possible objectives are to a large extent hierarchical; achieving results at the second level of objectives (CP plan) is facilitated by success at the first level (identification of opportunities), and to achieve results at the third level (continuous environmental improvement), one usually has to have achieved success at the first and second levels.

In addition, differences occur between working methods tailored to one industry sector and more general working methods. These appear in the formats used for data collection and evaluation, which can be either general or adapted to the industry-specific raw materials, processes, control parameters and waste streams, and the presentation of example CP options, which can either be cross-sectorial (general working methods) or industry-specific (industry-specific working methods). The classification of the six example CP working methods on objective and the scope of the working methods is elaborated in *Table 2*. The results can be used in the planning and preparation of future CP projects.

Terminology

The comparison of the various working methods is hampered by confusion about the terminology. The confusion is especially apparent when comparing the core study method of each of the example working methods. These are either assessment (PROGRES and PRECARI), prevention study (PROSA), study (or widening) phase (meat processing project) and evaluation (quick scan and CP indicators). Once again, confusion can be avoided and cross-fertilization enhanced by classification of the core methods used. A division can be made between indicators, scans, pre-assessments and assessments. *Table 3* contains a comparison of each of them on various methodological features.

Table 3 reveals huge differences between the four core methods, especially in terms of types of options generated, possible applications and call on (human) resources. For the continuation of CP it is important that the method goes beyond the identification of the 'ready-to-implement' options ('low hanging fruits'). New insights should be generated and elaborated into feasible solutions. In other words, it is highly beneficial

Table 1 Summary of key features of the example CP working methods

Features of the working methods	PROGRES	PRECARI	PROSA	Meat processing industry	Quick scan	CP indicators
Objective	Initiate an on-going company CP programme.	Develop a CP plan and evaluate the opportunities for implementation through permitting.	Develop a CP plan.	Develop a CP plan.	Identify most obvious CP options and evaluate their pay-back time.	Estimate the order of magnitude of the CP opportunities.
Expected result	Company possesses a coherent package of CP options and has learned to identify, evaluate and implement additional CP options.	Company possesses a CP plan and received recommendations for improvement of decision making with regard to strategic environmental issues.	Company possesses a CP plan and has been convinced of the desirability of implementation of this plan.	Company possesses a CP plan and has started the implementation of this plan.	Company has an overview of the most obvious CP options and their expected feasibility.	Company knows the order of magnitude of the possible environmental and economic benefits of CP to the company.
Company participation (tasks)	(1) Gather and analyse process data; (2) Generate, evaluate and implement options.	(1) Gather and analyse process data; (2) Generate, evaluate and implement options.	(1) Gather and explain process data; (2) Generate and implement options.	(1) Gather and analyse process data; (2) Generate (evaluate) and implement options.	Disclose available (environmental) data.	Calculate process parameters.
Method (CP option generation)	First round: brainstorm fed with qualitative source and cause evaluation and example CP options. Second round: brainstorm fed with improved, quantitative source and cause evaluation and technology reviews.	Brainstorm focusing on synthesizing ideas from various departments and/or disciplines (in companies) or focusing on applying example CP options (in hospital).	Brainstorm fed with source and cause evaluation (with quantitative data on key material flows) and example CP options.	Brainstorm fed with source and cause evaluation (with quantitative data on key material flows) and example CP options, supplemented by results of benchmarking in the industry sector.	Inventory of the results of past CP initiatives and company's reflection to the consultant's on-site review remarks and suggested example CP options.	Derivation of a potential estimate (based on results of CP demonstration projects, benchmarking studies and technology reviews), followed by comparison of the particular company's profile with this potential estimate.
Procedure	Extensive pre-assessment, followed by the parallel execution of assessments (for priority areas), feasibility studies (for CP options) and implementation of obvious CP options.	(1) Basic four-step approach without pre-assessment (in companies) or extensive pre-assessment followed by the parallel execution of feasibility studies and implementation of obvious options (in hospital). (2) Parallel evaluation of procedures in environmental decision-making.	First company visit for orientation and planning, followed by prevention study (= pre-assessment) and feasibility evaluation and planning by the consultants.	Quick scan as starting point. CP study based on pre-assessment with a very tight division between identification of environmental bottlenecks, source and cause evaluation and option generation.	Hardly any procedure: external analysis in order to identify, link and evaluate the company's own ideas and reactions to example CP options.	Hardly any procedure: external assessment of opportunities to improve the material and energy efficiency of the production processes.
Role of supervisors	'Process-orientated' and 'programmatic'.	'Programmatic' or 'process-orientated' focus.	First 'programmatic', later 'technical'.	'Programmatic' or 'technical' focus	Very limited; 'programmatic' focus.	Very limited; 'technical' focus.

Table 2 Classification of the example CP working methods on objective and scope

Objective	Scope (target industries)	
	General	Industry specific
<i>Level 3</i> Initiation of continuous environmental improvement	PROGRES PRECARI	
<i>Level 2</i> Development of a CP plan	PROSA	Meat processing project
<i>Level 1</i> Identification of obvious CP opportunities and/or priority areas	Quick scan	CP indicators

for the continuation of CP if the CP working method contributes to the development, evaluation and implementation of relatively radical environmental innovations. The combination of *Tables 2* and *3* suggests that the 'assessment' is superior in terms of contributing to relatively radical environmental innovations and of initiating continuous environmental improvement. As all projects summarize their achieved environmental improvements in different ways and no attention has been given so far to comparability of the results, it is not yet possible to prove that in practice an assessment is also superior in achieving environmental improvement. Nevertheless, it seems highly likely that an assessment will be superior in achieving actual long-term reductions of the environmental burden.

Linking working methods with the corporate learning process

The classification of CP working methods can also be linked with the different steps a company has to take in the learning, or transition, process from 'end-of-pipe' to 'cleaner production' thinking and acting. As in other learning processes, one might distinguish: obtaining attention for CP, generating interest in CP, generating and evaluating CP options, implementing CP options and integrating CP into the regular business operation. *Figure 1* depicts the scope of each of the CP working methods in this learning process.

First of all, it should be concluded from *Figure 1* that the working methods are weak in contributing to the strategic changes leading to the integration of CP into the regular business operations. Except for PRECARI, in which decision-making on environmental strategies has been separately evaluated, none of the example working methods pays explicit attention to the integration process. For PRECARI, only the hospital case study results have been published so far. In that case study, the evaluation of the decision-making procedures revealed several trends in the development of the organization, such as standardization of materials and practices (through protocols), decentralization of decision-making and implementation of Total Quality Management. This made it

possible to depict how CP might benefit from each of these organizational developments, and thus contributed to the incorporation of CP in the business operation¹⁶.

A review of the PROGRES project pinpointed the role of the supervisors (consultants) in initiating the on-going integration process. It was suggested that the supervisor should strive for achievements with regard to four success factors¹⁷. These are:

1. *achieving visible CP benefits*: for the environment as well as for the company's economic position;
2. *organizing a capable and motivated project team*: which at least should have the ability to understand how the facility operates, the authority and support to change the facility's operations, and the ability to maintain the CP spirit as old challenges are met and new opportunities arise;
3. *generating new insights*: in terms of both waste generation causes and CP opportunities;
4. *introducing a preventive environmental management (or care) system*: for instance by linking CP with the Total Quality Management System.

One further step is to investigate driving forces within the company for the continuation of CP. Detailed evaluation studies of CP programmes in a variety of industries are needed to draw conclusions about such key driving forces and to develop appropriate tools to activate these forces. In this perspective, one might take the evaluation study of waste reduction activities in the US organic chemical industry as a starting point. According to this study, the companies that had implemented one of three individual programme features – cost accounting, employee involvement, and leadership from both environmental and other (production) departments – had statistically significantly more CP activities, on average, than companies lacking these features¹⁸. Cost accounting could be either full (chemical-specific, multimedia cost accounting at the process level) or partial (at least chemical-specific or multimedia cost accounting at the process level). Employee involvement programmes include incentive reward programmes, training and ideas solicited from employees on a systematic basis.

Table 3 Characterization of core methods for CP

Features	Scan	Indicators	Pre-assessment	Assessment
Level of analysis	Company level	Company level	Plant level	Process level
Evaluation tool	Checklist	(Process) parameters	Process flow chart	Material and energy balance
Source identification	Ad hoc	Incorporated in the indicators	Inventory of input and output material flows	Balance of input and output material flows
Cause assessment	Ad hoc	Incorporated in the indicators	Qualitative	Quantitative
Option generation	On-site process review	During indicator development: based on technology reviews, benchmarking and example CP options	Brainstorm and application of example CP options	Brainstorm, application of example CP options, bench-marking and technology reviews
Main focuses of CP options generated	Good housekeeping (prevention of spills and leakages, enforcement of working instructions); Readily available input material alternatives (reduced toxicity, extended service life-time etc.); Equipment modification (improvement of measuring provisions).	Good housekeeping (optimal process parameters, rationalization of the production); Readily available input material alternatives (reduced toxicity, extended service life-time etc.); Equipment modification (process modification, optimal utilization of equipment).	Good housekeeping (improvement of operating practices and production planning and rationalization of the production); On-site recovery; Technology modifications (installation of recovery and/or control equipment, elimination of obsolete process steps); Product modifications (changes of packaging mode, elimination of toxics).	Process modifications (new production routes, alternative catalysts etc.); Equipment changes (more efficient equipment and lay out, new technologies); Input substitution (more efficient auxiliaries, use of secondary, renewable or biodegradable materials); Product modifications (minimization of the material content, energy-efficiency improvements, life-time extension etc.)
Type of supervision	'Programmatic'	'Technical'	'Programmatic'	'Process-orientated'
Possible applications	(1) Identification of most obvious CP options; (2) Identification of environmental bottlenecks; (3) Preparation of a fully fledged company CP project; (4) Establishing permitting strategies.	(1) Quantification of the possible CP benefits (economic and environmental); (2) Identification of the most obvious CP options; (3) Preparation of a fully fledged company CP project.	(1) Development of action plan for implementation of CP in the company; (2) Prepare a CP plan for permitting.	(1) Detailed evaluation of obvious and non-obvious CP options; (2) Evaluation of capacity expansion and/or renovation investments; (3) Development of long-term environmental strategies.
Expected cycle time ¹⁴	1 month	1 week	2 to 4 months	6 to 9 months
Necessary involvement from the company's staff	Low; one person	Low, one person	Medium; 2 or 3 persons	High; 3 to 5 persons
Necessary supervisory time (consultant/trainer)	2 to 5 working days	None ¹⁵	7 to 15 working days	20 to 50 working days
Example CP working methods	Quick scan	CP indicators	PROSA Meat processing project	PROGRES FRECARI (companies)

Figure 1 CP working methods linked to steps in the corporate learning process

In order to accelerate the company's self-interest in continuing CP, provision should be made to incorporate these driving forces into the CP working methods.

Additionally, we conclude from *Figure 1* that, in principle, CP working methods can be applied consecutively in the corporate transition process. Proper information dissemination (on, for instance, successful CP projects) contributes to obtaining attention for CP. Once attention has been obtained, CP indicators and/or a scan can be used for the preliminary identification of CP opportunities. This might result in interest from the company in CP. This, in turn, is necessary to start a pre-assessment in order to generate and evaluate the relatively obvious CP options. If proven feasible, these might be implemented by the company. The implementation of these relatively obvious CP options might have created additional commitment for CP, which might be necessary for the proper execution of an assessment. This assessment should in turn result in long-term CP opportunities. Once these have been identified, the company might decide to incorporate CP into its regular business operations.

Although it seems very logical to link the CP working methods, as in *Figure 1*, with the learning process, there are also several limitations to this approach. The most important problem is that none of the working methods has included provisions to guarantee that the company will continue with the next working method and thus proceed towards continuation and integration of CP. Additionally, when starting with the relatively simple CP working methods, one focuses on the 'low hanging fruits' which might not exist due to past (cost-reduction) activities. The absence of such evidently feasible CP options might in turn discourage companies from looking into more radical innovations with one of the more extensive CP working methods. Despite the apparent logic of linking

the CP working methods to the learning process, it is recommended to postpone the use of such an approach until more has been learned about how to encourage the integration of CP. In turn, it is advisable to focus on company characteristics when selecting an appropriate working method for introducing CP in a particular company.

Matching companies and working methods

Although it might be highly beneficial, both in environmental as well as in economic terms, for all companies to execute a fully fledged CP assessment, one might not expect the majority of companies (especially small and medium sized enterprises) to do so voluntarily in the short term because of the limited availability of (human) resources and know-how. This in turn, justifies the application of the other CP working methods. It is suggested that companies should be matched on the basis of a limited number of general characteristics to the most appropriate CP working method. This set of company characteristics should evaluate the expected ability of the company to manage the execution of each of the CP working methods and the expected magnitude and nature of the CP potential in the company. Our experiences so far have led us to propose three company characteristics for this matching.

1. *Size of the company.* The size of the company is thought to be highly illustrative of the capability of the company to manage the execution of one of the CP working methods. The larger the company, the easier it might be to allocate human resources to the execution of a CP assessment, and it is more likely that the company has specialized personnel able to generate and evaluate environmental innovation options. The number of employees might be taken as a first indication of the size of the company.
2. *Material and energy intensity of the production.* The material and energy intensity of the production is thought to be illustrative of the CP potential. One might expect that industries with a relatively high material and energy intensity (such as petrochemical and primary aluminium industries) have implemented all 'low hanging fruits' in order to cut energy and materials costs, which forces them to use a fully fledged assessment to identify additional CP options. At the same time, the possible benefits from environmental innovations might be highest in these industries, which justifies the investment in (human) resources to execute a fully fledged assessment. At the other end of the scale, industries with a relatively low material and energy intensity (such as garages and hospitals) tend to have overlooked energy and materials conservation opportunities, which enables them to achieve significant CP progress through implementation of 'low hanging fruits'. A lot of these obvious CP opportunities can be identified with relatively simply

CP working methods (such as scans and/or indicators).

3. *Types of processes.* The types of processes are thought to be illustrative of the nature of the CP options. Given the fact that CP options are often specific to the combination of unit operation and materials use, one might expect that industries with highly uniform combinations of unit operation and materials use (such as the printing and metal-working industries) face highly comparable CP options which can be generated through rather simple CP working methods. On the contrary, industries with relatively unique combinations of unit operations and materials use (such as tool manufacturing and production of microelectronics) will face highly specific CP options, which require more complicated CP working methods.

Three combinations of two company characteristics have been made in Figures 2, 3 and 4 linked with CP working methods. These figures use a division into three categories for each of the company characteristics in order to depict which CP working method might be most appropriate for a certain category of companies.

The use of these three figures is bound to have limitations due to the fact that the company characteristics are not independent and since there are no definite criteria for allocation of companies to one of the three categories on each company characteristic. Despite these limitations, it is felt that these figures are a useful starting point for selection of a CP working method for a particular company.

Concluding remarks

The comparison of working methods used in various Dutch CP demonstration projects shows that, although all projects claim to apply the same (PRISMA) working

Figure 2 Recommended CP working method with regard to size of the company and material and energy intensity of the production

Figure 3 Recommended CP working method with regard to size of the company and type of processes

Figure 4 Recommended CP working method with regard to type of processes and material and energy intensity of the production

method, substantial differences occur in all aspects of the CP working method. Various attempts have been undertaken to tailor methods for option generation, procedures for organizing CP activities and modes of supervision and guidance to specific company characteristics and available resources. The time has arrived to learn from the various applications and to abandon the concept of one working method being most appropriate for all kinds of companies.

This paper has introduced a framework for the classification of CP working methods into scans, indicators, pre-assessments or assessments. Although

additional evaluation studies might be needed for the actual verification, it is very likely that an assessment is superior in facilitating radical environmental improvements (or innovations) as well as in contributing to the integration of CP into the regular operation and management of a company. The application of simplified working methods is, however, justified, as one might not expect the majority of companies to execute voluntarily fully fledged assessments because of the limited availability of (human) resources and know-how. In addition, simplified methods can be very instrumental in identifying relatively obvious CP options and justifying their implementation, which in turn will result in significant short-term reductions of the environmental burden, and might be the starting point for on-going CP activities. The selection of an appropriate CP working method thus becomes an important factor in successfully planning a CP project. A balance should be found between not exceeding the company's ability and resources to execute the CP project (with a too-complicated working method), and ensuring expansion of the option inventory beyond the 'low hanging fruits' (not applying a too-simple working method). Three parameters have been given in order to guide the method selection. These were: company size, material and energy intensity of the production, and type of processes.

This comparative evaluation further proves that the working methods are still weak in stimulating the corporate transition process from end-of-pipe to CP thinking and acting. Additional research into the driving forces within various types of companies for the continuation of CP will be necessary in order to improve CP working methods in such a way that these foster the development of these driving forces.

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