Chapter 4
Input-Output Analysis and Cleaner Production

Annik Magerholm Fet, Cecilia Haskins, and Magnus Sparrevik

Abstract This chapter gives an overview of the basic principles for analysing material flows for production processes. This type of analysis is based on a calculation of materials going in and out of a process. Typical materials to be accounted for are energy, raw materials and other supporting materials. Likewise, outputs from a production process are waste of different types, emissions to air, water and soil, as well as noise, radiation, vibrations, and loss of heat. In an input-output analysis, the by-products from the process are also accounted for. The chapter also explains the principles of cleaner production starting with the motivation from corporate leadership to make production processes cleaner: to reduce waste and emissions and use material in a more efficient way. The concept of Cleaner Production (CP) also embraces strategic changes for making production and products cleaner and greener. However, the purpose of the chapter to provide information about basic principles for collecting information to be used in an environmental account for organisations, which will help them improve their overall environmental performance.

4.1 Introduction

The cleaner production methodology described in this chapter is based on an understanding and accounting of material and energy flows into a production process, the emissions, discharges and waste streams generated in the process and the by-products and final products (or service) that come out of the process. For the

A. M. Fet (✉)
Department of International Business, NTNU, Ålesund, Norway
e-mail: annik.fet@ntnu.no

C. Haskins
Department for Mechanical and Industrial Engineering, NTNU, Trondheim, Norway
e-mail: cecilia.haskins@ntnu.no

M. Sparrevik
Department for Industrial Economics and Technology Management,
NTNU, Trondheim, Norway
e-mail: magnus.sparrevik@ntnu.no

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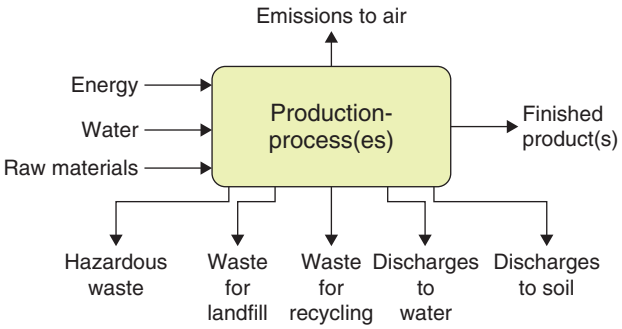

Fig. 4.1 Material flow scheme with inputs & outputs for single/series of production process(es)

purposes of this book, it is referred to as an input-output (I/O) analysis throughout. Typical inputs are materials (e.g. processed, recycled, reused or raw materials; natural resources), energy and services. Outputs are products (e.g., main products, by-products, recycled and reused materials), services, wastes (e.g., solid, liquid, hazardous, non-hazardous, recyclable, reusable), and emissions (e.g., emissions to air, effluents to water or land, noise, vibration, heat, radiation, light). A visual representation of these inputs and outputs is presented in a material flow scheme, see Fig. 4.1.

The operations of an organization may be logically grouped based on inputs to, and outputs from, their different physical facilities and equipment. Operations also include the supply to, and delivery from, them. This can be illustrated by a process flow diagram for the production site, such as the one which Pingmuanglek et al. (2017) produced for starch production.

I/O Indicators can further help to account and compile the inputs and outputs of the material streams of the process, form the basis for assessment of subsequent improvements and are often used to communicate quantitative information. The set of I/O-indicators are often referred to as the firm-level operational performance indicators (OPIs) (ISO 2021). A summary of material flows for each of the processes in a production, or the aggregated OPI-values, will then form the environmental account of the entire production site. OPIs are important when a company establishes its environmental aspects, goals and programmes for environmental improvements. It will show change in the environmental performances over time and is an essential part of the environmental management system of the company (see Chap. 7). An environmental account is also of great importance in providing the underlying information for cleaner production.

4.2 Defining Cleaner Production Strategies

Cleaner production (CP) comprises strategies that aim at reducing environmental impacts and impacts on health and safety resulting from products throughout their life cycle, from the extraction of raw materials to their elimination. It encompasses

concepts to minimise waste production; eco-efficiency; pollution prevention or green productivity. CP is relevant for companies with large quantities of emissions and waste, no overview of resource usage, material flows and waste generation, and high consumption of water, energy and other inputs. According to the action lines presented in Fig. 2.3 in Part I, Chap. 2, CP-principles can be summarized as precaution, prevention and integration, ranging from the macro to micro scale of policies, processes, and products. Prevention refers to proactive actions on the corporate operational level aimed at the causes of pollution. Rather than addressing emissions after they are released, the actions aim at the heart of the cause of these emissions. The measures may attempt to either close material cycles inside the industrial process or substitute hazardous materials with less hazardous ones. Prevention is a dynamic process within a spectrum of possible measures rather than a specific type of measure, focused on industrial processes that include considerations of both products and the nature of consumer demand (Jackson 1993).

4.3 Performing a Cleaner Production Project

CP implies a change of focus from the usual question of "How can we handle our waste and emissions?" to a more proactive set of questions, such as "Where do waste and emissions come from, how can they be avoided, and if unavoidable what other options are available?" An illustration of cleaner production strategies is given in Fig. 4.2. Emphasis when employing these strategies should ideally focus on *the left* branch of this hierarchy and only consider *the right* branch when all possible alternatives have been exhausted.

CP initiatives can be implemented by following the 5-step plan recommended by the US Environmental Protection Agency (USEPA 1992) as follows Sects. 4.3.1–4.3.5. This model has later been slightly revised by Baas (1995), and by Zhang et al. (2018), however the main approach follows a set of similar steps.

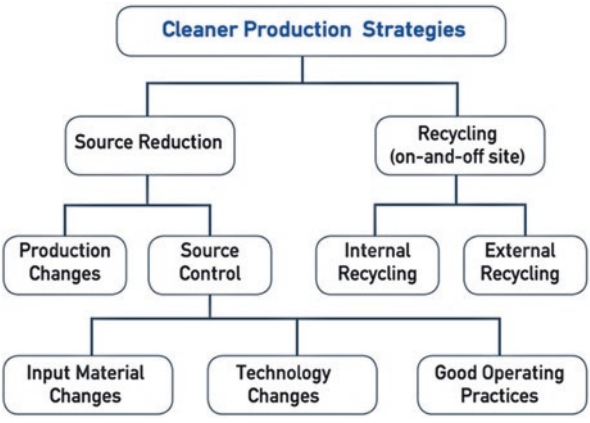

Fig. 4.2 Illustration of the principle for CP strategies (USEPA 1992)

4.3.1 Planning and Organisation

CP strategies suggest a variety of measures that contribute to reducing waste and pollution at source. After gaining management commitment for conducting a CP assessment (CPA), a specific issue, or set of issues, should be agreed upon as the target of the assessment project. A qualified team of assessors should be identified and organised as a task force to address the preparations and inspections needed.

4.3.2 Preparation

As an integral part of implementing CP, companies need to build their environmental account. An environmental account includes mapping of all material flows and an assessment of the impact on the environment caused by these flows, together with an environmental impact assessment of products and services. Essential to the preparation phase, is the collection and classification of available and relevant data and other corporate records regarding the assessment target(s). As options for improvement are identified, the activities will enter a feasibility analysis phase, as illustrated in Fig. 4.2.

4.3.3 Assessment Step

There are a wide range of methods available for generating ideas for CP improvements. Workshops and brainstorming sessions may be used. Methods for CPA may in addition include table-top exercises, checklists and inspections on site. All methods should ensure that participation is encouraged, that ideas are documented and that all ideas are given appropriate level of consideration.

4.3.4 Feasibility Analysis Step

Based on information gathered through the assessment phase, the different options are analysed to determine whether implementation of the options can be justified. Three types of feasibility studies are usually made before selecting an option for implementation.

- Technical evaluation (Is it technically executable with regards to the set demands?)
- Economic evaluation (Is it financially justifiable?)
- Environmental evaluation (Will it provide a satisfactory environmental solution?)

Technical Evaluation
The technical feasibility of proposed options must answer the question, "Will the suggestion reduce pollution and waste in the given situation?". Any proposed adjustments to the production facilities should consider physical obstacles to the actual construction as well as the potential impact on the specific requirements of the product. Of special interest are: the market availability of the required equipment; the commercial availability of proposed equipment; and the maturity, i.e., has the equipment been demonstrated and tested successfully and used in similar conditions? Questions related to availability and suitability are the primary concern of a technical evaluation for any promising option for pollution and waste reduction.

Economic Evaluation
Standard measures of financial return on any planned investments are used during the economic evaluation. This includes tools for analysing and comparing economic consequences of potential investments, such as pay-back on investment, internal rate of return, and net present value.

The simplest way to determine if a project is a good investment is to add all the savings and deduct the sum of all the expenses. Savings and expenses may be hidden in company accounts under different headings. As an example, the cost of waste disposal may be directly available in the accounts, however it is unlikely to specify in detail which materials are wasted and in what quantity. In addition, accounting for any lost labour, and production downtime, can be challenging. Certain costs may also be recorded as fixed, even they are variable. A valuable method for assessing costs and savings is conducted by holding thorough discussions with the responsible accountant together with staff from different parts of the operations and management. This might include a walk through the premises, which may reveal that certain expenses or savings are not included in the accounting, such as so-called overhead expenses. However, the team should focus on the main areas in order not to waste too much time on details and small amounts. It is also possible, that companies can reduce their overall risk, through the introduction of cleaner production measures which can have a positive influence on the economic evaluation.

Environmental Evaluation
Data collected in previous phases is applied to the analysis of internal and natural environments. The internal or working environment can have environmental effects on workers. A poor internal environment can manifest in a high absence rate and lower productivity in production. The natural environment encompasses the surrounding areas of the company, consisting of soil, air and water. Pollution of the natural environment affects the local community and can also have global consequences. This analysis requires knowledge about how the various production processes impact the natural environment. Benchmarks with regards to quantitative OPIs before and after a production change, a material change, a technology change or an operational change, become evidence for the objectives achieved.

4.3.5 Implementation

In this phase, the selected options are delivered according to the recommendations and plan of action in the final feasibility study. It is also noteworthy that this process is highly iterative. If the technical feasibility is incomplete, it may be necessary during this phase to revisit the earlier assessment phases before proceeding. As the company gradually identifies new targets for CPA, the overall benefits of CP and return on investments are realised.

When the company has completed a CPA in one part of the production line, the organisation has obtained the competence to use this experience in other parts of its operations. It can be challenging to prioritise improvement options resulting from a CP. It is obvious that options with high environmental benefit, low technical problems and high profitability should be considered first. Normal housekeeping measures will be at the top of the list and can usually be implemented immediately. Other criteria for prioritizing candidate options include the following:

- Comply with all existing environmental demands from regulatory agencies
- Evaluate demands from neighbours, insurance companies, banks and customers
- Avoid use of toxic substances whenever alternatives exist
- Reduce total consumption of materials and energy
- Continuously consider methods for closing material streams internally
- Investigate ways in which company waste can become a resource for others by establishing an industrial symbiosis

It is important that environmental concerns are prioritised before short term financial gains, and that environmental measures are compatible with long term investments, project plans and product improvements.

Plan of Action

Before moving on from this phase, the team should propose a plan of action that prioritizes and addresses execution of the most promising options. The plan of action should include a list of activities needed for the implementation and measurements, design, contact with the equipment providers, and other resource requirements. Some of the options may require competence outside the company, in which case, consultancy support should be considered. The plan of action should also consider if some of the options should be implemented as demonstration projects and whether it is possible to receive financial support to conduct such pilot projects. The execution of a demonstration project should also be described in the plan of action.

Additional Uses of the Feasibility Analysis Report

A completed feasibility analysis is useful for the company in many ways. The company benefits from an overview of the material flow in the surveyed work process; an overview of waste and emission streams, and which technical, economic and environmental challenges are connected to candidate measures for improving the natural and internal environment. A thorough report from the feasibility analysis phase provide auxiliary benefits beyond the initial purpose. Many governments demand a technical environmental analysis when issuing permits for emissions, and a good report can support this. In connection with increased demands on companies

to provide environmental reporting documentation, a complete report from a CPA provides a good starting point. The report also provides a strong foundation for registering environmental improvements after completion of the initial study.

4.4 Conclusion

CP is a broad concept with implications for application at all levels of society. This chapter has mainly focused on CP processes. CP strategies can be adopted by individual companies, by a cluster of industrial enterprises, at regional and state levels of government and at a global level through treaties and international agencies. Indications are that compliance with CP principles of waste and emission avoidance and reduction render positive results for all three pillars of sustainable development – social, environmental, and economic. There remains a need for a consolidated strategy that combines the many different instruments for promoting collaboration in the direction of CP by bringing together all relevant stakeholders.

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