Research Report 2

JOHAN FACHT

EMISSION CONTROL COSTS IN SWEDISH INDUSTRY

An empirical Study of the Iron & Steel and Pulp & Paper Industries

IUI
THE INDUSTRIAL INSTITUTE FOR ECONOMIC AND SOCIAL RESEARCH

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FOREWORD

By the end of the 1960's a more active environmental protection policy was initiated in Sweden. The Environment Protection Board was set up in 1968. More stringent emission standards were enforced. In order to dampen the economic consequences to the firms, the government has subsidized emission control investments since 1969.

The Industrial Institute for Economic and Social Research considered it to be of great interest to evaluate the effects of the environment protection policy in Swedish industry and therefore accepted an invitation to participate in a large research program entitled "Environment, Natural Resources and Society", initiated in 1971 at the Stockholm School of Economics by professor Erik Dahmén. The present study of the costs of reducing discharges of industrial residuals is made by Econ.lic. Johan Facht.

The study covers the first four years, 1969-1973, of the subsidy program. It is limited to analyses of emission control measures in the iron & steel industry and the pulp & paper industry. These were the two branches that have received the largest subsidies. The statistical basis for the cost estimates consists of the applications for government subsidies of emission control investments at plants in operation before July 1, 1969. Data for the study were obtained at the Environment Protection Board - the agency to which the firms had to apply for the subsidies.

Financial support for the study was given by the Swedish Central Bank Tercentenary Fund and by the Marianne and Marcus Wallenberg's Foundation for Technical and Economic Research in the form of a personal research grant to the author.

Stockholm in April 1975
Lars Wohlin

PREFACE

In 1971, professor Erik Dahmén of the Stockholm School of Economics launched a research program entitled "Environment, Natural Resources, and Society". Financial support for this program was given by the Swedish Central Bank Tercentenary Fund. The present study, which is a part of this research program, also benefitted from a personal research grant given to the author by the Marianne and Marcus Wallenberg's Foundation for Technical and Economic Research, and I would like to express my sincere gratitude to the chairman, Dr Marcus Wallenberg, for this generous support.

Throughout the study, I was fortunate enough to receive encouragement and support from a number of persons. My greatest obligation is to professor Erik Dahmén whose pioneering work in the field of environmental economics inspired me to undertake this study in the first place and who has actively contributed to the study, not only by "administrative" support but also by continuous encouragement and guidance. I am also indebted to Dr Lars Nabseth, former director, and Dr Lars Wohlin, director of the Industrial Institute for Economic and Social Research, for the great privilege to work in such a stimulating environment as the IUI. Dr Wohlin has throughout the project shown a generous interest in my work and has also made a number of invaluable contributions.

During part of the project I was fortunate enough to have the assistance of an engineer, Civ.ing. Anders Grufman, whose technical expertise proved particularly valuable during the work with the process classifications and during the data collection stage.

Special thanks should also be extended to Prof. Karl-Göran Mäler, Dr Bo Carlsson, and Ekon.lic. Bertil Lindström who were all generous enough to struggle through early versions of the manuscript making a great number of valuable comments and suggestions to improvements. At a seminar at the Stockholm School of Economics I also received valuable comments from Mrs Margareta Johannesson and Mr Lars Bergman. I am also greatly indebted to Civ.ing. Börge Borgström and Civ.ing. Erik Sandhagen for their assistance during the data collection stage.

I have also been unusually fortunate in receiving, throughout the project, the generous assistance of the Environment Protection Board. In fact, without their cooperation and support the present study would never have been completed. Since the number of persons at the EPB who contributed actively to my work is very large indeed, I cannot mention more than a few of them. Among those I would like to thank particularly are Mr. Bengt Aplander, Mr. Lars Lindau, Mr. Lars Hansson, Mr. Hans-Roland Lindgren, and Mr. Nils Jirvall.

I also wish to express my appreciation to Prof. Sven Eketorp, Royal Institute of Technology, for his advice in connection with the work on the classification of sub-processes in the iron and steel industry, and to Mr. Sten Forslund, Technical Director, and Mr. Bengt Westin, Chief Engineer, at the Domnarvet Steelwork, for their kindness and help during my visit to Borlänge.

Since part of the present study was carried out during visits at other institutions, I would like to thank those who made these visits possible. In this connection my first thanks go to Prof. James M. Gere, Department of Civil Engineering, Stanford University, who made my five-months stay at the section for Environmental Engineering both stimulating and pleasant. Grateful thanks also go to Professors Dale Carlson, Gardner Brown Jr., and Ralph Johnsson at the University of Washington in Seattle, Wash. who all made my stay at the university most valuable from both a professional and personal point of view.

I also wish to thank Mrs. Wera Nyrén, Mrs. Alice Nilsson, Mrs Marianne Frisell, and Mrs. Gudrun Dahlberg for their typing and proof-reading of the various versions of the manuscript, and Mrs. Berit Lindberg who has made some of the more complicated tables readable.

Needless to say, I am solely responsible for any remaining errors of fact or interpretation.

Stockholm in April 1975
Johan Facht

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

During the last decade, environmental quality management has gradually become one of the leading issues in the public debate on economic policy. The primary reason for this mounting interest in environmental issues is the increased awareness of the risks of undesirable changes in ecological systems (and thereby also in the welfare of man) that might occur as a result of uncontrolled discharges of so-called waste products or residuals (i.e. products with no economic use at existing prices) into the environment.

The choice between using the natural environment as a recipient of residuals or as a source of other environmental services is sometimes mutually exclusive, and the management of the natural environment can therefore be regarded as a problem of allocating scarce natural resources among competing ends. Since environmental resources generally can be characterized as "common property resources" whose services do not pass through markets, there will be no market-determined prices on these services to guide their allocation to the highest value use. The fact that the market system as an institution cannot allocate environmental resources means that other institutions will have to carry out this function. Consequently, the allocation of environmental resources has become an important field for governmental decision-making.

The problem for those charged with the responsibility of environmental policy decisions is both to choose the "optimal" level of environmental quality and to design a management system such that this level is attained at minimum cost to society. In order to facilitate decision-making, economic models that include various kinds of environmental relationships have been developed. Most of these models are conceptually divided into three parts: one part in which the relationships between inputs and outputs of man's production and consumption activities are described; a second part which describes the physical, chemical, and biological changes that the residuals undergo after their discharge into natural environmental systems, and a third part relating concentrations of residuals to damage to receptors. The first part of these models, i.e. the part which concentrates on the individual discharges (be they firms, households, or municipalities) of residuals and on the costs to those economic agents of reducing or changing the mix of their discharges, has been at the center of interest for a large number of economists. The reason for the interest in developing such models is the notion that accurate identification of existing discharges, and estimation of the initial incidence of costs of reduction or modification of these residual loads, can provide a basis for assessing the future effects (and costs) of alternative control programs, and thus facilitate the choice of environmental policy measures.

1.2 SCOPE OF THE STUDY

The present study is basically an attempt to identify the amount of residuals generated in each of the basic processing steps that constitute the production process and to estimate the initial impact of the costs of reducing or modifying the discharges of these residuals.

Data for the study were obtained from the Environment Protection Board - the agency to which firms had to apply for government subsidies of emission control investments. The subsidization scheme had been set up simultaneously with the Environment Protection Act (July 1, 1969) as an incentive for plants already in full operation by July 1, 1969, to speed up the investments necessary for compliance with the Environment Protection Act. Thus, data have been obtained only for those emission control investments that were carried out between July 1, 1969, and June 30, 1973, by plants in existence before July 1, 1969. Needless to say, these data do not cover the total investments for emission control by these industrial branches during the period in question. For example, most emission control investments by new plants were excluded. The reason for this is the fact that since emission control investments in new plants were not entitled to any subsidies, firms had no incentives to supply any information about the costs of these measures either in applications to the Franchise Board for a franchise, or in applications to the Environment Protection Board for an exemption. Thus, cost data for this part of total emission control investments were impossible to obtain from these sources.

The calculations of the annualized costs of emission control measures were further complicated by the lack of data on operating costs of emission control equipment. Since subsidies were given in proportion to investment costs only, operating costs were not always specified. In some cases, therefore, these costs had to be calculated with the help of standard engineering data.

The study is limited to an analysis of two major industrial sectors - the iron and steel industry and the pulp and paper industry. The principal reason for this choice was the fact that these sectors account for a large portion of industrial residuals discharges in Sweden.1) Another important reason was the fact that these two industries received almost two thirds of the total government subsidies for emission control measures during this period and that the available cost data therefore were concentrated to these industries.

1.3 GENERAL OUTLINE OF THE STUDY

The present study is divided into basically three parts. The first part (Chapter 2) consists of a summary of the economic theory of environmental quality management, the second part (Chapter 3) of a description of the methodology used in the study, and the third part (Chapters 4-8) of an analysis of Swedish environmental policy between 1969 and 1973, and its economic impact on the iron & steel and pulp & paper industries.

The first sections of Chapter 2 contain a definition of the concept of environmental quality and a discussion of the nature of production and consumption processes. The major part of this chapter, however, consists of a discussion of the mechanisms for the allocation of environmental services. In the final two sections of this chapter, the principal technological and policy options for environmental quality control are presented.

Chapter 3 contains a discussion of some theoretical and practical problems of environmental quality management, and a description of the methodology used in the present study.

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1) In 1969, roughly 90 % of total BOD_7-discharges and 20 % of total SO_2-discharges originated in the pulp and paper industry. The iron and steel industry, in turn, accounted for approximately 20 % of total emissions of particulates.

The first chapter of the empirical part of the study (Chapter 4) describes the characteristic features of Swedish environmental policy and the basic principles underlying the Environment Protection Act, the National Physical Planning Guidelines, and the Act on Product Hazardous to Man or to Environment are summarized. The chapter is concluded with a short description of the principles behind the program of subsidization of emission control investments.

Chapter 5 presents some figures on the macro-economic impact of the emission control investments undertaken by Swedish industry between July 1, 1969, and July 1, 1973. The chapter contains a description of the distribution of both the emission control investments and the subsidies among industries, regions, and over time. The last two sections of the chapter discuss the effects of the emission control investments on both employment and total discharges.

The economic impact of the Swedish environmental policy on the iron & steel and pulp & paper industries is analyzed in Chapters 6 and 7. The presentation in these chapters follows the same pattern and both chapters start with short descriptions of the structure of the industries. Each chapter also contains general descriptions of the different steps of the production processes and the raw residual loads associated with these steps.

The final chapter contains a short discussion of the quality and the possible uses of the data and concludes with an attempt to assess the degree to which the objectives of the study were fulfilled.

CHAPTER 2

ECONOMIC ACTIVITIES AND THE ENVIRONMENT

2.1 THE CONCEPT OF ENVIRONMENTAL QUALITY

The standard dictionary definition of the term environment is "the aggregate of surrounding things, conditions and influences". This wide definition has made it possible to use the term in a variety of contexts. Thus, one talks not only about the natural environment but also about the social environment, the cultural environment, the working environment, etc.

The services rendered by the various elements of the natural environment are economic goods in the sense that people are willing to pay to receive more of them, i.e. they are scarce relative to demand. These services include residuals assimilation and dispersion services as well as life-sustaining services, amenity, and raw materials supply services. For purposes of economic analysis, therefore, those natural conditions and raw materials that render economically valuable direct or indirect services to man are termed natural resources. There are two categories of natural resources, renewable resources (flow resources) and non-renewable resources (stock resources). In general, some form of man's activities must be applied to these resources in order to enable man to benefit from their services. From this definition, it follows that in an economic sense, not even the supply of so-called non-renewable natural resources is a fixed quantity, but rather a quantity which changes as a result of changes in relative prices and which becomes greater and more varied with the scientific and technological advance by man. Since the supply of natural resources (thus defined) is a function of man's economic and technical ability to develop them, alternative natural resource development policies inevitably will exist.

If environmental quality is defined as the level and composition of the flow of all environmental services except the services as recipient of waste products and raw materials supplier, then a deterioration of environmental quality can be defined simply as a reduction in the quatity and/or quality of these services. The term pollution, then, is not necessarily synonymous with residuals discharges and should therefore be used only when residuals discharges lead to a reduction of environmental quality. It must, of course, be recognized that there is always a certain risk that even very small (and seemingly harmless) discharges of residuals cause direct or indirect long-range effects that we are unable to perceive at the present moment.

The need for an economic analysis of environmental quality management thus originates in the recognition that the environment's capacity to assimilate various residuals without negative effects on environmental quality is a scarce resource, the use of which has to be economized. The extent to which the environment will be used as a recipient of residuals will depend partly on the viewpoint (i.e. anthropocentric or biological) of the society in question and partly on how the risks of undesirable ecological changes are estimated and evaluated. A central issue in environmental quality management is therefore the formulation of social objectives under uncertainty. This problem will be discussed further below.

2.2 THE NATURE OF PRODUCTION AND CONSUMPTION SERVICES

Mankind plays a central role in the complex biogeochemical cycles of the biosphere by the fact that it has acquired the ability to modify the operation of ecosystems.1) In spite of his sometimes quite limited

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1) The two main components of natural systems are living organisms and nonliving substances. These two components are closely related and interact upon each other to produce an exchange of materials between living and nonliving states. Any area of nature where these two components are interacting to produce an exchange of materials is referred to as an ecological system or ecosystem.

Nonliving (abiotic) substances are the basic inorganic and organic compounds of the environment, such as water, carbon dioxide, oxygen, calcium, nitrogen and phosphorus salts, amino acids, and so on. The living (biotic) components of an ecosystem are generally classified into three groups, namely (1) producers, (2) consumers, and (3) decomposers. The mechanisms regulating the storage and release of nutrients, the growth of organisms, and the production and decomposition of organic substances are not yet understood in every detail. A recurring theme in the discussions on this subject is, however, the homeostatic character of these mechanisms. This tendency of ecosystems to approach a state of equilibrium is often referred to as "the balance of nature". In modern ecology emphasis is often put on the fact that mankind is a part of complex biogeochemical cycles and that man's ability to change and control the operation of ecosystems has been increasing faster than his under-

cont.

understanding of the resulting ecological effects, man makes frequent use of this ability in order to increase his own immediate welfare. In these efforts, man has gradually learned to transform certain natural conditions and raw materials into forms that match his preferences better than do their original forms.

The basic postulates of the first two laws of thermodynamics make it natural to look upon so-called production processes as merely transformation processes into which flow inputs of mass and energy and out of which flow the same amounts of mass and energy as were put into the processes.[2] Expect for the transformation of small amounts of mass to energy in nuclear reactions, this holds for all production

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1) cont.
standing of the results of such changes. The fact that man has the power to modify the operation of ecosystems does not mean, however, that all "man-made" changes are by definition bad (or that all changes that are not man-made are good). In fact, many of the ecological systems that man regards as valuable parts of his environment are man-made in the sense that man has modified the operation of the system in order to promote his own welfare. Thus, the concept of "ecological balance" can be given different interpretations depending upon whether one takes a more anthropocentric or a more biological view of the problem. Common to all interpretations of the concept, however, is the view that an ecosystem's usefulness to man can be permanently lost if the limits of the homeostatic mechanisms are exceeded by the activities of man.

[2] The science of thermodynamics is the study of the interrelationships between heat and other forms of energy. It is characteristic for this branch of natural science that quite far-reaching deductions can be drawn from a small number of postulates.

The first law of thermodynamics (or the law of conservation of energy) states that the energy contained within a closed system (i.e. its internal energy) is constant, no matter which energy transformations take place within the system. According to Einstein's principle of relativity, mass and energy are different measures of the same thing expressed in different units, and the law of conservation of energy is but another form of a law conservation of mass. The second law of thermodynamics may be stated in many different ways. One often-used formulation is that no process involving energy transformation will spontaneously occur unless there is a dissipation of energy, or differently expressed, an increase in entropy.

According to the first law of thermodynamics, a system isolated from all others will always maintain a constant amount of energy, and therefore, when the second law of thermodynamics is spoken of as the law of the dissipation of energy, no loss in energy is meant, but rather a loss in the availability of energy for external purposes. This is, consequently, also the precise mening of an increase in entropy.

processes.[3] For production processes, thus defined, only part of the energy or mass outflow will constitute the product - unless they are "ideal" processes in which all inputs are fully converted to outputs. The residual flows will, by definition, have no economic use at existing prices and the producers' only interest in these residuals is therefore their minimum cost disposal. For various reasons (to be discussed below), the cheapest way of disposal (at least to the individual producers) has long been direct discharge into the environment.

Against the background of the laws of thermodynamics, the process of "consumption" (the term commonly used by economists) has to be viewed in a similar way. The household sector may receive services from the goods it buys or it may transform these goods by mechanical, chemical, or biological processes, but it never "consumes" them in a physical sense. "Consumption goods" will eventually also become residuals. Thus, the processes of extraction, production, and consumption should be viewed as transformation processes and in the long run, all materials flows through these processes will be balanced by equal flows back to the environment in the form of residuals. This interdependency is illustrated in Figure 2:1.

If the flows between the different sectors are measured by mass, a long-run materials balance for the economy can be written:

$$F_{EP} = (G_{PC} + G_{PP} + G_{PT}) + (R_{PE} + R_{TE} + R_{CE}).$$

If the residual discharges ($R_{PE}+R_{TE}+R_{CE}$) are of such a quantity and/or quality that the environment's assimilative capacity is exceeded, the quantity and/or quality of the services rendered by the environment to the household sector (S_{EC} = life-sustaining services, recrea-

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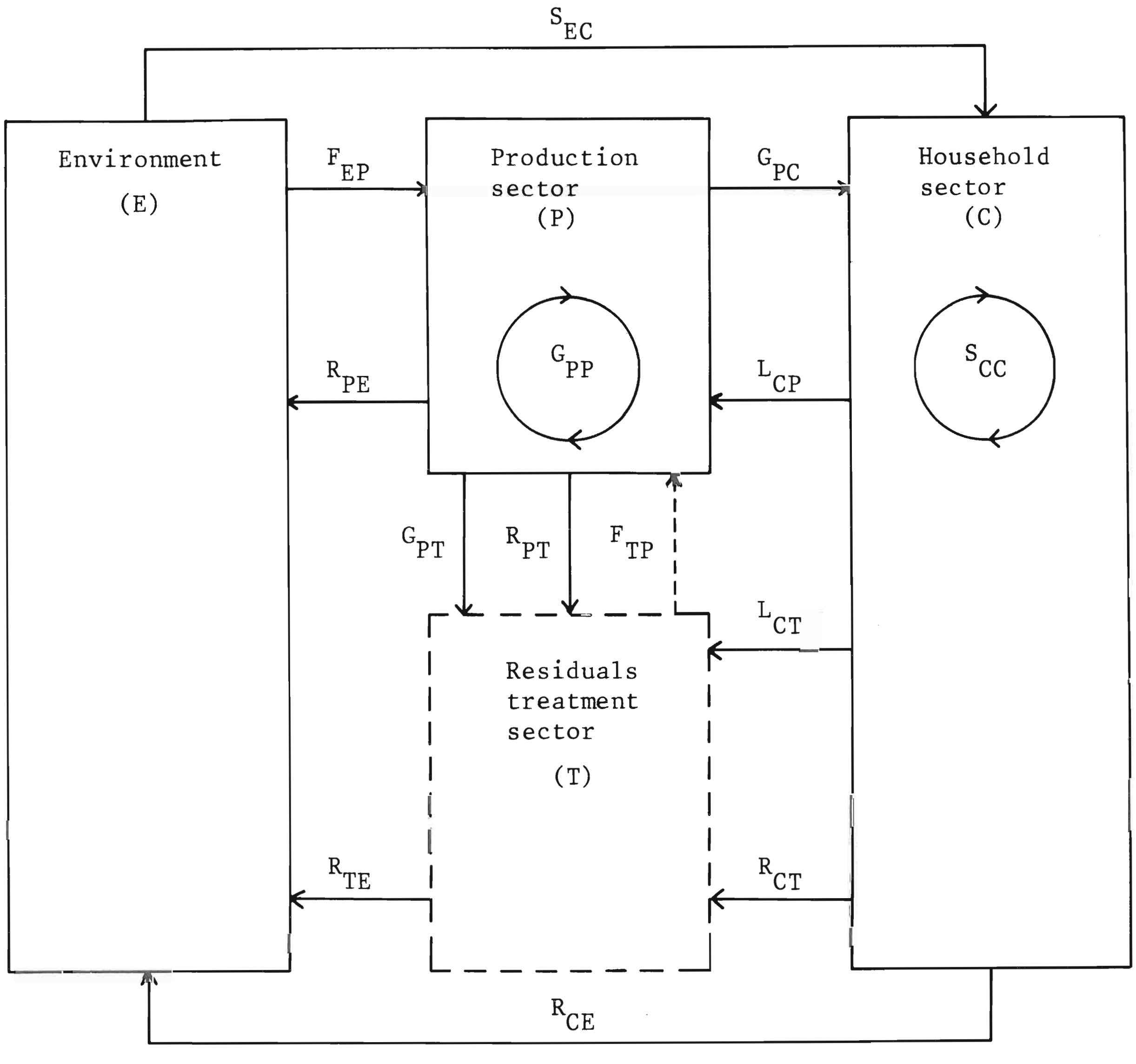
3) This also holds for an economy which is closed (i.e. an economy with no imports or exports of either factors, goods, or residuals) and where there is no net accumulation of stocks (i.e. plants, equipment, inventories, consumer durables, or buildings). It is also important to note here that in accordance with the law of conservation of mass, various forms of residuals treatment do not "destroy" the residuals in a physical sense, but merely change their form. This means that after treatment, the residuals can be accounted for either as (a) materials returned to the production processes, or (b) "secondary" residuals (generally in a different form) to be discharged (sometimes at a different time and/or location).

Figure 2:1. A materials balance view of the economy.



Symbols: F = Raw materials
G = Goods
S = Services
L = Labor
R = Residuals

Subscripts: 1 = Origin
2 = Destination

tion services, amenities, etc.) will be reduced. The need for environmental quality management originates in the fact that there is no automatic mechanism that will ensure an optimal flow of such environmental services. The problems of allocating environmental services will be discussed in the next section.

2.3 THE ALLOCATION OF ENVIRONMENTAL SERVICES

2.3.1 The market mechanism and environmental quality management

From an economic point of view, the management of environmental quality can be regarded as a problem of allocating scarce natural resources among competing ends. The choice between using the natural environment as a recipient of residuals or as a source of other environmental services is, as has been pointed out above, often mutually exclusive. In an ideally functioning market system the problem of resource allocation is solved through the automatic generation of information in the form of prices of factors, commodities, and services. If all factors, commodities, and services pass through markets that are perfectly competitive (and where a number of other necessary conditions are satisfied as well), prices will guide resources into the use which maximizes economic welfare.

Corresponding to the physical flows of materials between various intermediate (production) sectors and the consumption sector, there are, in general, reverse flows of money. The physical flows of materials from and back to the natural environment, however, are only partly reflected by corresponding money flows (namely in the cases of land rents and payments for non-common property raw materials inputs). There are three classes of physical exchange which are not fully matched by corresponding economic transactions:

(1) Private use of "common property" resources as inputs to production processes. (This use may also have an impact on the residuals-assimilative capacity of these resources.)

(2) Private use of the assimilative capacity of the natural environment to decompose or dilute residuals.

(3) Inadvertent or unwanted material inputs to production (or consumption) processes.

These so-called "market failures" can be partly explained by the special character of these resources. Exchange in a market depends on the existence of property titles (or rights of disposition) to the things that are to be exchanged. Many of these resources, however, can be characterized by indivisibility, i.e. these resources cannot be divided into separate units, the use of which are independent of the use of other units. This means that these "common property" resources cannot be subject to exchange in a market and they have therefore, in general, been transferred at zero price. This is not because they are not scarce relative to demand or because they confer no service to the user but simply because there exists no social institution which would permit these resources to be "owned" and exchanged in the market.

Thus, the user of a "common property" resource does not in his decision take into account the costs he imposes on others. In economic terminology the use of the resources is said to cause "technological external diseconomies". This problem is not a new one in economics and the first references to it in the economic literature emerged as early as in the 1880's and the "classic" work by Pigou was originally published in 1920.4) A characteristic of the analyses of technological external diseconomies that appeared in a large number of articles during the fifties and sixties is that they dealt with externalities as comparatively minor aberrations from optimum situations in competitive markets and that they limit themselves to a discussion of externalities between two parties.5)

In our previous discussion, where production and consumption activities were described within the framework of the materials-balance concept, it was pointed out that the generation (and possible discharge) of residuals in production and consumption processes must be regarded as a more or less inevitable side-effect of these processes. The external effects associated with the discharge of such residuals are in no way exceptional cases that can be dealt with adequately through simple ad hoc arrangements - they are, on the contrary, rather pervasive features of the economy. Another characteristic feature of these externalities is that the number of individuals affected generally is quite large and the lack of realism in the assumptions underlying discussions of two party externalities therefore limit their

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4) Sidgwick, H., Principles of Political Economy, London, 1883, and Pigou, A.C., The Economics of Welfare, London, 1920.

5) See for example, Scitovsky, T., "Two Concepts of External Economies," Journal of Political Economy, April 1954; Coase, R., "The Problem of Social Cost," Journal of Law and Economics, Vol. III, October, 1961; Davis, O.A. & Whinston, A.B., "Externalities, Welfare and the Theory of Games," Journal of Political Economy, June 1962; Buchanan, J.M. & Stubblebine, W.C., "Externality," Economica, August 1963; Turvey, R., "On Divergencies Between Social Cost and Private Cost," Economica, August 1963.

direct utility for policy recommendations. This "weakness" (from a policy point of view) of a large part of the discussion of externalities partly explains the efforts that have been made in developing operational analytical methods capable of handling the problem of externality within a broader framework.

To recapitulate our arguments so far, we have emphasized that if the residuals decomposing capacity of the natural environment is a scarce resource (which seems to be a fairly realistic assumption), then a decentralized voluntary exchange process cannot be free of uncompensated technological external diseconomies unless (1) all inputs are fully converted into outputs with no residuals generated, and all final outputs completely vanish in the process of consumption, or (2) property rights are so arranged that all relevant environmental services can be exchanged in competitive markets. Since neither of these conditions hold in actual life, the management of these resources must be achieved through some mechanism of collective decision.6)

2.3.2 Public environmental quality management

2.3.2.1 General theory of environmental quality management

The fact that an optimal allocation of common property resources will not be achieved by voluntary exchange in a market, means that some other institutions will have to carry out this function. In order to be able to establish the objectives of their environmental policies in such a way that the resulting environmental quality will represent a "social optimum", the decision-making authorities need some kind of measure of the social costs of achieving and maintaining various levels of environmental quality as well as some measure of the social benefits associated with these various levels.7) The general rule of choice is that resources should be allocated to improvements of environmental quality as long as marginal social benefits are greater than marginal social costs. This problem of choice can be illustrated by means of a simple diagram (Figure 2:2).

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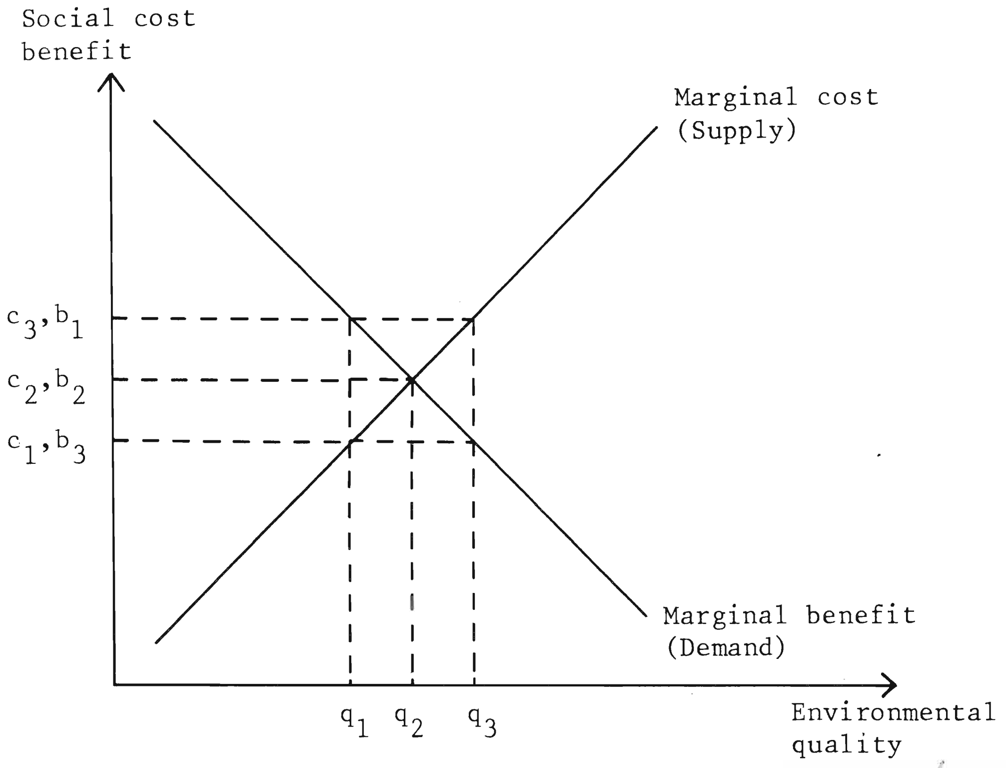
6) In the following discussion of public environmental quality management, it is implicitly assumed that the gains of intervention will outweigh the institutional costs of intervening.

7) The concept of social cost is essentially an "opportunity cost" concept. The social cost of some particular commitment of resources thus consists of the benefits given up in the most productive alternative use of these resources.

Figure 2:2. Model for optimization of the level of environmental quality



Abatement
Reduction.

At environmental quality level q_1, the marginal cost of a small improvement is c_1 whereas the marginal benefit is b_1. Since $b_1 > c_1$ environmental quality should be improved. At level q_3, a small reduction of environmental quality would imply a cost reduction of c_3 and a loss of benefits of b_3. A reduction of environmental quality would, consequently, be to the advantage of society. At environmental quality level q_2, however, marginal costs and marginal benefits of a small change in the quality level are equal, and no change in environmental quality would improve society's welfare.

The extent to which such a general formulation of the goal for an environmental policy is of any help for the decision-maker, however, depends on the availability of adequate data costs and benefits, respectively. The previously mentioned absence of markets in which the benefits of environmental policy measures can be adequately evaluated, has made it necessary to tackle this social choice problem by a number of other methods.

(a) Cost-effectiveness analysis

One possible approach to the social choice problem associated with environmental quality management is to let experts in various fields suggest maximum permissible concentrations of various residuals (or minimum environmental quality standards). The rationale for such a procedure bears a sharp resemblance to the "merit want" argument.[8)] It is also worth noting that this approach implies damage functions of a very particular shape. Residuals concentrations up to the level of a standard are implicitly assumed to have no cost, whereas discharges resulting in concentrations above that level are assumed to have infinite costs.

An alternative approach to the problem of choosing environmental quality standards is for the authorities to make estimates of the minimum costs of achieving alternative levels of environmental quality and thereafter let the "optimum" level be decided through some political choice process. Calculations of the minimum costs of achieving various physical objectives are called "cost effectiveness analyses". In order to be of help in the social choice process, however, such calculations must be extended to involve a sensitivity analysis of costs with respect to different values of the specified objectives. Thus, the authorities must compute the rates of change of the minimum achievable project cost with respect to each standard. Such computations indicate the costs of increasing or decreasing the standard, information that is particularly valuable when the standards will be determined through the political decision process.

The major disadvantage of the "standards"-approach lies in the difficulties of determining the size of the discharge reductions necessary for complying with a given environmental quality standard. This is due to the fact that our knowledge of ecological interrelationships is often insufficient for establishing with certainty the relation between various emission standards and various environmental quality standards. The decision-making authorities will therefore have to make some simplifying assumptions about these relations. Since this will

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8) "Merit wants" are wants considered so meritorious by the authorities that their satisfaction is provided for through the public budget, over and above what is provided for through the market and paid for by private buyers.

introduce an element of uncertainty into the analysis, these relations should, preferably, be expressed as probability distributions.[9)]

The problem of expressing various quality standards in terms of corresponding emission standards is further complicated by the fact that the environment's capacity to assimilate certain residuals varies not only among recipients but also over time for each recipient. The uncertainty resulting from the stochastic changes in the assimilative capacity could be handled by estimating the probability distributions of these changes. This means that the relation between various environmental quality standards and their corresponding emission standards could be expressed as compounded probability distributions. With the help of such probability distributions, the decision-making authorities could calculate the costs of those discharge reductions that would meet different environmental quality standards with a given degree of certainty.

Furthermore, the existence of regional differences in assimilative capacity necessitates different discharge reductions in different regions for the achievement of a given level of environmental quality. Consequently, if the authorities intend to establish emission standards (in addition to environmental quality standards) these should be differentiated in order to reflect differences in assimilative capacity between various regions. Thus, if the objective is compliance with national environmental quality standards, this would probably not be

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[9)] Some economic theorists have attempted to distinguish between risk and uncertainty. The usual basis for such a distinction is whether the probability distribution of outcomes is known or unknown. This distinction has been subject to serious challenge and it has been suggested that the use of the term uncertainty be restricted to those cases in which the outcomes of projects are dependent on the action of one rational opponent (or a small number of them) and, consequently, are not random variables, though their value is unknown. In such cases it is not possible to express possible outcomes in terms of a probability distribution. The appropriate tools for the analysis of such situations are provided by the theory of games. For the purposes of the present study, however, this distinction seems to be relatively unimportant (except when environmental management decisions are arrived at through the process of bargaining) and the terms risk and uncertainty are therefore used inter-changeably.

A detailed discussion of these terms can be found in Knight,F.H., Risk,Uncertainty and Profit, Boston, 1923 and von Neumann, J. & Morgenstern, O., The Theory of Games and Economic Behavior. Princeton, 1953.

achieved by establishing national emission standards.[10]

Thus, by the very nature of some environmental problems, environmental quality management is sometimes best conducted at the subnational (i.e. the local, the regional, etc.) level. Ideally, the jurisdiction of the agency responsible for environmental quality management should coincide with the environmental "problem-shed". A suggested mechanism for collective choice decisions on public goods issues (among which environmental management questions belong) is a representative government of general jurisdiction. Even if existing governments of general jurisdiction could be redesigned so as to approach the model of representative governments, these institutions will not suffice as far as environmental management is concerned. The main reason is of course that the jurisdiction of these institutions seldom corresponds to the environmental "problem-shed" boundaries. These boundary problems are indeed difficult to solve, but in the solution suggested by E.T. Haefele, the higher levels of government would limit themselves to setting "boundary conditions" for the levels of government that make the detailed collective choices.[11]

In spite of the difficulties of translating (regional) environmental quality standards into emission standards, cost-effectiveness analysis can be a helpful tool for decision-making in situations where there are no adequate measures of the benefits associated with the action under consideration. In cases where such measures do exist, however, an alternative tool of analysis is the so-called cost-benefit analysis.

(b) Cost-benefit analysis

The kind of problem for the solution of which cost-benefit analysis can be a useful instrument can often be described as a maximization problem. A commonly used description of the purpose of a cost-benefit analysis is: to enable the decision-maker to choose that course of action which maximizes the difference between the present value of all

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10) It is, of course, possible that an optimum environmental policy would include regionally differentiated environmental quality standards. This line of thought is often implicit in national physical planning schemes.

11) See Haefele, E.T., Environmental Quality as a Problem of Social Choice, in A.V. Kneese & B.T. Bower (eds), Environmental Quality Analysis: Theory and Method in the Social Sciences. Baltimore, 1972.

benefits and costs under given constraints. Such a general formulation of the purpose immediately raises a number of essential questions related to the four analytical steps:

(1) Which consequences should be included in the analysis? (The problem of identification.)

(2) How should consequences be measured? (The problem of quantification.)

(3) How should consequences be evaluated? (The problem of evaluation.)

(4) Which are the relevant constraints and which is the relevant criterion of decision? (The problem of choice.)

In each of the above-mentioned four steps of analysis, the analyst is faced with substantial practical problems. In an economy characterized by a high degree of interdependence among the various sectors, the number of factors to be included in the analysis will be very large. Even if the purpose of a cost-benefit analysis is to provide an over-all estimate of the consequences of alternative courses of action, it will generally be necessary to concentrate on some of the consequences. Since there is no simple criterion for selection of "essential" consequences, the analyst must estimate the decision-makers' preferences in this regard.

Another problem frequently facing the analyst is that consequences which have been identified as essential are difficult to quantify and/or evaluate correctly. In a cost-benefit analysis, two flows of values are compared: a flow of costs and a flow of benefits. The time-preference functions of the general public generally imply that distant future values are discounted compared to present values. In order to make future flows of costs and benefits comparable to present costs, therefore, these flows have to be appropriately discounted.

A number of economists have recommended the use of a discount rate based on "social time preference" to appraise public investments. In a world in competitive equilibrium (implying, among other things, a perfectly functioning capital market) there would be no difference between a rate based upon time-preference and one derived from opportunity cost. It is generally very difficult (if not impossible) to find criteria by which the social time-preference could be determined.

One of many important questions in connection with the choice of discount rate is the treatment of uncertainty or risk. Some of the risks associated with environmental management decisions result from engineering uncertainties, some from the stochastic nature of changes in the assimilative capacity of various environmental media, and some from changes in the social and economic factors on which the outcome of a project will be heavily dependent. A number of procedures for dealing with risk have been developed in economic theory. The probabilistic approach emphasizes that no single expected return figure can adequately represent the full range of possible alternative outcomes of a risky undertaking. The difficulty with the probabilistic approach, however, is that probability distributions are seldom known in detail. The most commonly used method - the risk-discount method - has the advantage of being relatively easy to handle. Its basic shortcoming is that it does not give the analyst any instructions on how to calculate the appropriate value of the discount factor which consequently must be estimated on the basis of some more or less subjective judgement. Since the risk-discount method does not take account of the full range of possibilities and their associated probabilities, it can justly be argued that this method ignores elements that are important in an effective calculation of an optimal investment policy.

As pointed out above, cost-benefit analysis is applicable in situations where voluntary exchange takes place incompletely and where the resource allocation decisions have to be made by some governmental agency. The costs associated with such governmental projects, or system of projects, consist, in general, of the costs of the private goods purchased by the agency implementing the program, and it is common practice to use market costs as acceptable approximations of social costs. This, of course, necessitates a long string of assumptions, among which one is that all markets are in competitive equilibrium.

In cost-benefit analysis, benefits can be measured in different ways depending upon the character of the problem under scrutiny. For decisions in connection with environmental quality management, the general rule of choice is, as pointed out above, to reduce the concentration of residuals in the environment as long as the marginal benefits (in this case the reduction in the damage caused by the residuals) exceed the marginal costs of achieving the reduction. Thus, in order to be able to determine an economically optimal degree of discharge reduction, the decision-making authorities need to know the relationship between various concentrations of residuals and the resulting damage. Ideally, these "damage functions" should be stated in monetary terms.

In conventional welfare economies the concept of monetary damage is generally defined in two different ways.[12] The most commonly used definition of a reduction in environmental quality is the minimum amount of money with which the individual must be compensated in order not to feel worse off as a result of the reduction in environmental quality. This basic definition refers only to the size of the necessary compensation and says nothing about whether this sum should actually be paid or not.

The scope and complexity of the empirical measurements required, plus the practical problems to handle income-distributional questions, make it difficult to achieve an optimal (i.e. efficient <u>and</u> equitable) allocation of environmental resources through decisions based exclusively on cost-benefit analysis. In spite of the risk of non-optimal results, the general responsibility for the provision of public goods must, in a democratic society, be borne by politicians together with their other responsibilities. Thus, the evaluation of the benefits of public goods will in the end always be a political problem, however useful the inevitably partial cost-benefit analyses might be in assisting the decision-making process. The importance of this fact for the development of environmental management models has been elegantly stated by Robert Dorfman:

> "The fundamental trouble with benefit-cost formulas is that they ignore politics, whereas the environment is politics; not only now when it is in fashion, but always because we all share the same public environment and most of us share the costs of controlling it and the benefits of exploiting it. The clear implication for interpreting environmental models is that they have to include political considerations. A proposed control policy that is politically unpalatable is no better than one that violates the law of conservation of mass. Perhaps, economic and political laws are more absolute than physical ones; at least we have displayed a great deal more ability to overcome physical obstacles than social ones. A few, very recent, environmental models

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12) Depending upon whether one takes the situation before or after the change as a basis for comparison, one talks in economic theory of the "compensating variation" and the "equivalent variation".

do attempt to inject political considerations. A great deal more will have to be done along these lines." 13)

2.3.2.2 Environmental management models

In order to overcome some of the problems faced by cost-effectiveness and cost-benefit analyses, attempts have recently been made to develop general interdependency models for environmental quality management. In the first major attempt to develop a comprehensive model for environmental quality management, the law of conservation of mass and energy was used as the point of departure for the construction of a general equilibrium model of the Walras-Cassel type.14) The shortcomings of this first attempt as far as empirical applicability was concerned, initiated a considerable amount of additional research aiming at the development of quantitative models within the general equilibrium framework.15)

Most of the models developed so far consist of three main components:

(a) Models relating inputs and outputs of selected production processes and consumption activities at specific locations within a region. These models, generally of the linear programming type, explicitly recognize the physical links between the three principal forms of a residual - i.e. airborne, waterborne or solid. These models also permit choices among production processes, raw material input mixes, by-product production, materials recovery, and in-plant changes, all of which can reduce the total quantity of residuals generated. The generation of residuals is therefore not assumed to be fixed either in form or in quantity. The models generally also allow for choices among treatment processes and hence among the possible forms of the residuals to be disposed of

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13) Dorfman, R.,"Modelling Through", Interfaces, Vol. 3, No. 4, August 1973, p. 7.

14) Ayres, R.U. & Kneese, A.V., "Production, Consumption, and Externalities". American Economic Review, June, 1969, pp. 282-297. Ayres, R.U., Kneese, A.V. & d'Arge, R.C., Economics and the Environment. A Materials Balance Approach. Baltimore. 1970.

15) Russell, C.S. & Spofford, W.O., "A Quantitative Framework for residuals Management Decisions" in A.V. Kneese & B.T. Bower (eds), Environmental Quality Analysis: Theory and Method in the Social Sciences. Baltimore. 1972.

in the natural environment and, in some models, also among the locations at which residuals can be discharged. One of the basic components of this part of the models is so-called industrial process models.

(b) Environmental models which describe the physical, chemical, and biological changes in the residuals after their discharge into the natural environmental systems. Between the points of discharge and receptor locations, the residuals may be either diluted, transformed from one form to another, accumulated or stored, or transported to another place. It must be noted in this context, however, that most models assume that the changes that any particular residual undergoes are independent of the presence of other residuals. In consideration of the relatively high frequency of phenomena like photochemical smog etc., this does not seem like a particularly realistic assumption. The problem is, however, that once physical, chemical, and/or biological interactions among residuals in the environment are introduced, the models become vastly more complicated. The same is true for models which explicitly incorporate the impact on living things.

(c) A set of receptor-damage functions relating the concentration of residuals in the environment and the impact on living things to the resulting damages, whether these are sustained directly by humans or indirectly through their impact on material objects or on such receptors as plants or animals in which man has a commercial, scientific or aesthetic interest. These functions, relating concentration of residuals and impact on species to damages sustained by the receptors should ideally be stated in monetary terms.

The linkages between the components of these models can best be explained by a description of the method of optimum seeking. The first step is to solve the inter-industry linear programming model without any restrictions (or charges) on the discharge of residuals. The second step consists of using the resulting initial set of discharges as inputs to the models of the natural environment. The resulting ambient concentrations and impacts on living things are then used as arguments of the damage functions and the marginal damage can be determined as the change in damage following from a unit change in a specific discharge. In the next round of calculation, these marginal damages are used as interim effluent charges on discharges in the linear model and that model solved again for a new set of production, consumption, treatment, and discharge activities. If the size of the consecutive steps is appropriately constrained and if functional forms have the appropriate characteristics this procedure will converge to a local optimum.

Optimization models of this type imply the availability of a considerable amount of detailed information not only about specific plants within the region but also about what happens to the residuals after they are injected into the environment. In order to describe in greater detail the data needed for a successful application of models of this type, it is useful to discuss the various components of these models somewhat further.

a. Models of the production sector

In the attempts to construct general economic models for environmental management, considerable progress has been made in the development of quantitative models of the production sector. The purpose of such models is to analyze the individual residuals-dischargers (be they firms, households or municipalities) and to calculate the costs to those agents of reducing or changing the mix of their discharges. Since these cost models are generally only a part of general economic models for environmental management, they are, as mentioned above, normally linked to models of the natural environment. Some models are constructed so as to reflect the market interrelations between the various economic agents, as, for example, in an input-output model. The reason for the development of production sector models is that for purposes of environmental policy choice, the identification of existing residuals discharges and the estimation of the initial impact of the costs of reducing or modifying this load are of vital importance. Although most of the models constructed so far have been optimization models designed to find the cheapest way to comply with exogenously given emission standards or ambient standards, etc. much work based on input-output tables has not involved optimization, but has rather had the character of simulation. The method of simulation can be very useful provided there is a mechanism by which to choose among the generally very large number of alternative outcomes.

Models under the general heading of optimization models are usually constructed so that selected parameters can be varied and alternative solutions found. When such models are used for analysis of the consequences of alternative discharge or ambient quality standards, they provide policy-makers with information on the costs of complying with a given standard and the added costs (or cost savings) of changing the standards. The choice between optimizing with respect to discharge or ambient standards largely depends on the nature of the environmental models linked to the production sector models. In the absence of adequate models that link discharges of residuals to ambient quality, the discharge standard approach will have to suffice. It is important to recognize, however, that apart from this basic choice, there are a number of other problems that the model builder will have to solve if the models are to be capable of aiding the decision-makers. One problem is the choice between static and dynamic models and another, equally important, is the choice between deterministic and stochastic models. Another problem, still, is to what extent it is necessary to be able to identify the points of discharge geographically.

Stochastic and dynamic elements are generally very difficult to handle adequately in optimization models and it is therefore important to recognize that these models can never provide a complete basis for decision-making. They should, rather, be regarded as tools which might possibly reveal some nonobvious effects of various policies and, at best, aid in quantifying them.

In view of the large number of problems facing the model builders it might be useful to look a bit closer at some production sector models in order to see how some of these problems have been treated.

a.1 The Russel-Spofford Model

The Russel-Spofford model is designed for an analysis of residuals management problems in specific regions. It is conceptually divided into three parts: (1) a linear programming model in which the residuals discharges from man's production and consumption activities are determined; (2) environmental models in which mathematical approximations of natural processes are used to transform discharges into ambient concentrations; and (3) a part in which these ambient concentrations are compared to exogenously given standards or evaluated through a set of receptor-damage functions.

The first part of the Russell-Spofford model deals simultaneously with the three major categories of residuals - airborne, waterborne, and solid - and reflects not only the initial generation of residuals but also the physical links between various forms of materia and energy as implied for example by the various residuals treatment alternatives open to the economic agents. Apart from the traditional costs of residuals treatment and disposal, this part of the model also incorporates the non-treatment alternatives available for reducing the level of residuals generation. Thus, the model includes options for reducing the generation of residuals through input substitution, process change, recirculation of residuals-bearing streams, and materials recovery.

The linear programming model of the production sector can in the first iteration be solved either with no restrictions or prices on the discharge of residuals or with a trial set of effluent standards or charges. This kind of model can thus be used to calculate the aggregate costs of simultaneously meeting certain production and environmental quality requirements.

In view of the growing public concern with the income-distributional effects of various economic policy measures, it is not, however, a matter of indifference to whom the costs (and benefits) accrue. In order to improve the model in this regard, Russell and Spofford have formulated the production sector model so as to include constraints on the distribution of both the costs and the benefits of possible environmental quality management policies.

The Russell-Spofford model can be seen as an important step in the development of a quantitative framework to assist regional authorities in making decisions about residuals management policies. The difficulties of constructing models that are comprehensive in the sense that they consider all linkages and all alternatives are so well known that it is unnecessary to repeat them here. In order to reduce the risk that the decision-maker draws the wrong kind of conclusions from the analysis, it is important to specify which aspects of reality are not included. Thus, the simplifying assumptions made in the didactic version of the Russel-Spofford model are:

(1) that a linear model is a good description of the production sector;

(2) that prices do not change;

(3) that time does not enter as a decision variable in the production sector model;

(4) that the physical world is deterministic and steady state;

(5) that no interactions among residuals in the environment occur (relaxed in later versions of the model), and

(6) that damage can be expressed as functions of single residuals only (also relaxed in later versions of the model).

The pervasiveness of the externalities-problem necessitated, as was pointed out above, a general equilibrium approach. The Russel-Spofford model is still, basically, a partial equilibrium approach for one specific region. Prices and costs (except the costs of reducing residuals discharges) are exogenously determined and neither interindustry nor interregional relationships are explicitly included. In spite of these shortcomings, the model is still a very useful analytical tool that helps the regional decision-maker to identify the various kinds of information necessary for the decisions. Important research tasks can be found in each of the model's three building blocks. In the production sector part of the model, the task would be to develop linear activity vectors describing the available alternatives for reduction of residuals discharges and to link these vectors in an interindustry model. The need for additional research for the development of both environmental models and receptor damage functions is now well recognized. Whether the challenge that this truly interdisciplinary research task represents will be met or not remains to be seen, however.

a.2 Input-Output Models

Input-output analysis is basically a way of taking into account the interdependence between the various sectors of an economy. This interdependence arises out of the fact that each sector in varying degrees employs the outputs of other sectors as inputs. Input-output analysis thus describes the level of output of each sector in terms of its relationships to the corresponding levels of activities in all the other sectors (determined by the exogeneously given vector of final demand). In the more complicated multi-regional and dynamic versions, the input-output approach permits an analysis of the spatial distribution of output and consumption of various goods and services and of their change over time. Some attempts have been made to incorporate the analysis of externalities into the input-output framework.16) Although the input-output models are able to capture some important interindustry relationships they have some serious shortcomings as well. Some of the simplifying assumptions generally made in most applications of the method are particularly serious in connection with an analysis of the problem of residuals. The most limiting among these assumptions are:

(1) Given coefficients of production, i.e. in any production process, all inputs are employed in rigidly fixed proportions and the use of these inputs expands in proportion with the level of output. Since the models are based on predetermined production technology, the policy-maker will not be able to consider the use of alternative technologies as a method of reducing the generation of residuals.

(2) The "generation" of residuals through the application of fixed coefficients which excludes the possibility of analyzing alternative ways of influencing the generation of residuals.

(3) The separation of residuals control activities from basic production processes which rules out many design options affecting residuals generation.

In the recent development of production sector models efforts have been made to include both economic and technological elements. An example of this is the so-called Materials-Process-Product model.17)

a.3 The Materials-Process-Product Model

The starting point for the Materials-Process-Product (MPP) model is detailed classification schemes of: (a) materials, where the principle of classification is the physical form of the materials (i.e. an extension and elaboration of the "solid, liquid, gas" trichotomy); (b) processes, in which so-called "macroprocesses" are broken down into a number

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16) See for example: Leontief, W., "Environmental Repercussions and the Economic Structure: An Input-Output Approach", Review of Economics and Statistics, August 1970, pp. 262-271.

17) Ayres, R.U., "A Materials-Process-Product Model" in A.V. Kneese & B.T. Bower (eds), Environmental Quality Analysis: Theory and Method in the Social Sciences, Baltimore, 1972.

of process-elements or "microprocesses";[18] and (c) products, which are grouped in accordance with the "Standard Industrial Classification" or SIC code.

The basic line of thought in the original version of the MPP model is that all possible production processes could be described as sequences of basic process elements taking into consideration all constraints upon the sequences of microprocesses imposed by the states and properties of the materials used. In a later version of the model, however, a substantially different view has been adopted.[19] In the first version, the "space of technological possibilities" was regarded as a continuum and the observed process differentiation was the result of more or less random explorations of this "space of possibilities" rather than the result of some evolutionary process. This view implied the assumption that macroprocess changes occurring as a result of changes in economic conditions would basically consist of rearranging sequences of unit operations and more efficient use of energy. The later version of the model, in contrast, takes the view that processes tend to evolve as distinguishable "species" and that each industrial process represents an optimal (or sub-optimal) choice from among a very large number of competing possibilities. The way in which most macroprocess innovations achieve their economic advantage is through the utilization of cheaper inputs. Such input substitution is made possible, for example, through the utilization of new microprocesses. Once a new microprocess (e.g. a new chemical reaction path) has been specified, the process of optimization (or sub-optimization) will lead to the development of a relatively efficient combination of components and physical flow patterns.[20]

b. Environmental models

The production sector models described above can, as pointed out, be

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[18] In chemical engineering terminology, microprocesses involving physical changes are called unit operations whereas microprocesses involving chemical changes are generally called unit processes.

[19] See Ayres, R.U. & Kneese, A.V., Models of the Activity Analysis of Production, Consumption, and Externalities. Unpublished mimeograph. Resources for the Future, Inc., Washington, D.C. 1973.

[20] An application of this model can be found in: Ayres, R., Saxton, J. & Stern, M., Materials-Process-Product Model. A Feasibility Demonstration Based on the Bottle Manufacturing Industry. International Research Corporation. Arlington, Va. 1974.

solved with constraints on the availability of not only ordinary resources but also on environmental resources. Thus, various limitations can be placed on the amount of residual material and energy which may be discharged to the environment. With the help of these industry models, the private costs of complying with alternative limitations can be determined. Since the level of private costs will always be of importance for environmental management decisions, this is useful general information. Thus, these industry models are important components of larger models for environmental quality management. For an analysis of the effects of various residuals discharges on the quality of the environment (or rather the environmental services), however, these models must be combined with models of the impact of residuals discharges on ecological systems. The connection between industry models and environmental quality has been accomplished through the use of "diffusion" models for the atmosphere and watercourses. These models are constructed in such a way that quantities of residuals discharged at some location (x) can be translated into ambient concentrations at some other location (y).21)

In these models, the various environmental media are usually divided into a number of blocks within which environmental conditions are regarded as uniform. Each block contains a set of differential equations where the rates of flow of materials across the boundaries of the blocks and the rates of biochemical transformation of these materials within the blocks are described as functions of the conditions within the blocks. In those cases where physical, chemical, or biological interactions among residuals in the environment are excluded, the equations describing the transformation of residuals between discharge and receptor locations can be expressed in linear forms for steady-state deterministic conditions so that the linkage can be made via coefficients.

Through the use of various environmental models it is possible to solve the industry models subject to different environmental quality

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21) See for example: Teller, A., "The Use of Linear Programming to Estimate the Cost of Some Alternative Air Pollution Policies", Proceedings of the IBM Scientific Computing Symposium. Yorktown Heights, N.Y., October 22-25, 1967; Thomann, R.V., "Mathematical Model for Dissolved Oxygen", Journal of the Sanitary Engineering Division, Proceedings ASCE, Vol. 89, No. SA 5 (1963); Kelly, R.A., "Conceptual Ecological Model of Delaware Estuary" in B.C. Patten (ed.), Systems Analysis and Simulation in Ecology, (Vol. 3). Baltimore, 1974.

constraints rather than only to different effluent constraints. Since the diffusion models are not limited to a single source of discharge, they can translate discharges from multiple sources to concentrations at multiple receptor locations. Even though computational requirements can sometimes be quite large, models of this kind can be used to calculate the minimum private costs of achieving a specified ambient standard (or set of standards).

c. Damage functions

The estimation of monetary damage as defined in the preceding chapter faces several difficult problems of measurement and requires some special assumptions about the impact on income distribution. The fact that the outputs of environmental management actions are almost always of a "public goods" character means that they are provided to large groups of people simultaneously and without one person's consumption of the good affecting the consumption of others. When the supply of a good (be it private or public) changes, however, both resource allocation and income distribution are affected. The income distribution problem associated with the provision of public goods characterized by "jointness of supply" is particularly difficult due to the fact that the consumption of such goods cannot be differentiated among consumers on the basis of their voluntary choice in markets. Even if the discussion is limited to changes which satisfy the Pareto criterion (i.e. that at least one individual is made better off without any other individual being made worse off) there is, in general, no way to be sure that equating incremental cost with the sum of incremental willingness to pay (i.e. incremental benefits) will lead to a welfare maximum except when the welfare function has a very particular form and it is a matter of indifference to whom the benefits accrue. The pre-distribution of income cannot be maintained except through an elaborate system of side payments tailored to each individual. Such a system of payments is, however, a practical impossibility.

The use of monetary damage functions is further complicated by the fact that the damaging effect of a given residuals discharge is heavily dependent upon the natural environmental conditions which prevail when the discharge is made. Since the residuals assimilative capacity of the environment is sometimes subject to random fluctuations, the effects of a given reduction of residuals discharges should be expressed by a change in the probability distribution of the quality level. In the case where it is possible to attach a monetary value to each possible outcome, information of the probability distribution would thus allow the computation of the mathematical expectation of monetary damage.[22] However, this expected monetary damage cannot be substituted for the "true" monetary damage unless the individual is completely indifferent to risk. In most of the literature on the problem of risk it is assumed that individuals are risk-averters and, therefore, it does not seem very realistic to maintain here that individuals are, in fact, indifferent to risk.[23]

2.4 TECHNOLOGICAL OPTIONS FOR ENVIRONMENTAL QUALITY CONTROL

In the preceding sections a number of definitions basic to the problem of environmental quality management were presented. To summarize, environmental quality was defined as the level and flow of all environmental services except the service as recipient of residuals and the raw materials supply services. In the discussion of the nature of production and consumption processes, it was pointed out that according to the law of conservation of mass, these processes have to be regarded as transformation processes out of which flow the same amounts of mass and energy as were put into the processes. It was also emphasized that the non-existence of "ideal" processes implies that the desired product constitutes only a part of the mass and energy outflows. Those parts of the flows that have no economic use at existing prices were termed residuals. This "economic" definition of the term explains why the producers' only interest in them is their minimum cost disposal. It

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[22] For a survey of the recent theoretical and empirical development in this field, see Mäler, K.G. & Wyzga, R.E., <u>Environmental Damage Functions: Their Estimation and Utilization</u>.OECD.Paris,1975.(Forthcoming)

[23] The process of measuring risk consists of basically two steps. The first of these steps is to estimate the probabilities of the possible outcomes of a specific course of action. The second step, in turn, consists of an evaluation of the effects of the possible outcomes. If the individuals are risk averters they might be willing to pay quite a high premium to eliminate the possibility (no matter how small) of an outcome with catastrophic effects. The present public debate concerning nuclear reactors is an illustration of this point.

was also pointed out that since the choices between using the environment as a recipient of residuals or as a source of other environmental services are sometimes mutually exclusive and since their services to such a large extent are characterized by non-market-ability, decisions on the allocation of environmental services have to be made through some collective decision-making process.

At this stage it is important to emphasize the fact that there are four basic technological options for environmental quality control independent of the choice of objectives for society's environmental policy.[24) These four options are: (I) reducing the rate of throughput of materials and energy in the production and consumption processes; (II) altering the residuals so as to make them less damaging to the environment; (III) choosing the time, the rate, and the place of discharges so as to minimize the damage; or (IV) increasing the residuals assimilative capacity of the environment through various forms of investments.[25)

The rate of materials throughput can be reduced by (1) reducing the overall level of economic activity or (2) decreasing the material and energy input requirements for producing a given level of output. A reduction in material and energy inputs per unit of production, in turn, can be accomplished by (a) increasing the technical efficiency of materials and energy use, (b) increasing materials recovery and recycling, and (c) altering the composition of output.

A reduction of the overall level of economic activity would, if all other things are kept equal, reduce the level of residuals discharges. This alternative is likely to be the most uneconomical of all since it does not take any advantage of the possibility of changing the ratio of throughput per (monetary) unit of output.

Decreases in the material and energy input requirements for producing a given level of output can be accomplished in any different ways. If economic considerations could be set aside, there are generally a large number of possibilities for alterations of almost every

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24) For a more thorough discussion of these options see Freeman III, H.M., Haveman, R.H. & Kneese, A.V., The Economics of Environmental Policy, New York, 1973, and Kneese, A.V. & Bower, B.T., Managing Water Quality: Economics, Technology and Institutions. Baltimore, 1968.

25) A classification of available control measures is presented in appendix to this chapter.

industrial process. The basic reason for not adopting available, technically more efficient processes is, in general, their economic unattractiveness at the existing set of prices. Thus applications of technically more efficient methods of production will only occur as the result of either changes in relative prices or technological changes (be they exogenous or "induced"). Administered changes in relative prices could, in principle, be used by the authorities as an environmental policy too. Such price changes might also be used to stimulate technological improvements in certain fields.

As far as increasing materials recovery and recycling are concerned, the mechanisms of relative-price changes and technological changes should logically operate in the same direction. The principal obstacle to materials recovery and recycling presently is the high cost of recovery relative to the value of the recovered materials. If the (social) costs of discharging residuals into the environment is levied upon the dischargers, or if the price of new material inputs from the environment rises, or if technological change lowers the cost of materials recovery, recycling will become economically more attractive.

The third way of altering the relationship between GNP and materials and energy throughput (i.e. changing the composition of GNP) can partly be accomplished through the same kind of changes as the prededing two alternatives. Thus, the shifts in consumption patterns that are necessary in order to achieve a change in the composition of output such that the production of goods that generate small amounts of residuals (in their production as well as in their consumption) is increased at the expense of goods that generate large amounts of residuals, might be accomplished by the use of special taxes designed to change relative prices. Another possibility would be to make goods more durable, since increased durability would mean that the goods would need replacement less often which, in turn, would lead to a smaller flow of residuals per unit of time. Increased durability of goods could be accomplished by devising special taxes that stimulate design changes and the use of different materials.

The second category of technological options for environmental quality control includes a large number of possibilities for changing the form of various residuals by biological, chemical, or mechanical processes so as to make them less damaging to the environment. As pointed out above, residuals treatment processes all obey the law of conservation of mass. Consequently, no residuals treatment processes result in an "annihilation" of the residuals in a physical sense. All that such processes can accomplish is a change in the form of the residuals. After treatment, the residuals must be accounted for either as materials returned to the production processes or as "secondary" residuals to be disposed of.

The third group of technological options (i.e. choosing the time and place of residuals discharges so as to minimize the damage) originates in the previously emphasized fact that the assimilative capacity varies not only among different recipients but also over time for each recipient. A skillful administration of this technological option could lead to substantial improvements in environmental quality at relatively low costs.

The fourth class of options, finally, (i.e. increasing the residuals assimilative capacity of the environment through various forms of investments) primarily includes measures to increase the assimilative capacity of water courses by means of low-flow-augmentation, in-stream aeration, etc. Since these measures may involve significant economies of scale and since their benefits may have the characteristics of a public good, they generally require direct action by the authorities.

2.5 POLICY OPTIONS FOR ENVIRONMENTAL QUALITY CONTROL

Apart from the numerous problems of arriving at an optimal social choice, there are also large problems of implementing a chosen environmental policy. The two basic management options available to the responsible agency are either to set up direct regulations for various types of discharges and to use the enforcement powers of the government to ensure compliance, or to use various economic incentives to such an extent that compliance is achieved voluntarily. The measures used in the first of these approaches are generally referred to as regulative measures.

2.5.1 Regulative measures

The somewhat loosely defined term regulative measures includes such different policy measures as (1) licensing or franchising of certain kinds of activities, (2) product and/or raw materials standards,

(3) zoning regulations, and (4) emission standards.[26] All these measures could in principle be used to achieve a desired reduction of residuals discharges. However, the amount of information required in order to achieve the desired reduction of emissions at minimum social costs by the use of these measures is quite large. Given the desired reduction of discharges of a particular residual, the total treatment cost for this discharge reduction is minimized when the marginal treatment costs are equal for all dischargers. Since treatment cost functions are likely to be different for different dischargers, the regulative authorities must, in order to be able to allocate the permissible total discharges optimally by the use of any of these measures, know the marginal treatment cost functions of all dischargers. Since it is highly unlikely that such information can be collected by a central authority, there is obviously a large risk that an environmental policy based on the use of regulative measures will lead to an inefficient allocation of resources.

It should, however, be noted that a cost-minimizing allocation of discharge permits (franchises) could be achieved if the regulative authority would sell these permits to the highest bidders. The same result could be achieved if firms were allowed to trade these discharge permits among themselves.[27]

A difficulty associated with environmental policy in general (and the use of regulative measures in particular) is enforcement. In fact, the enforcement problems have, in general, been underestimated in most discussions of environmental policy measures. This important point has been formulated in the following way:

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[26] The problems associated with the translation of environmental quality standards into corresponding emission standards were discussed in section 2.3.2.1.

[27] In the first case, it is assumed that firms do not have the "right to discharge residuals", and that all revenues from the sale are collected by the government agency. In the second case, firms are assumed to have the legal right to discharge residuals into the environment and that these rights can be sold to anybody. The sale and resale of discharge permits will lead to an efficient allocation of the environment's assimilative capacity. Whether the income distributional effects in the second case will be equitable or not, depends on (among other things) how discharge permits are initially distributed. For a further discussion of franchise trading, see Dales, J.H., <u>Pollution Property and Prices</u>. Toronto,1968.

"No mistake is more prevalent in models of the effects of mandatory controls than to assume that they are 100 per cent effective. They are not. Quite frequently people simply disregard the regulations and accept the occasional fines as part of the cost of doing business. Or they fight the controls, as the long history of litigation over requirements for waste-water treatment illustrates. At any rate it is an unscientific mistake to presume that ordering something to be so makes it so.

Nevertheless, virtually all models that deal with the effects of mandatory controls presume prompt and universal compliance and introduce the effects of those controls simply by reducing pollution injection rates to the prescribed levels. This does not render such models valueless, provided that one is careful to interpret them properly. They then tell us how the controls would affect the environment, and perhaps social and economic well-being, if they were 100 per cent effective. This is often useful information, but it should not be confounded with a forecast of the effects of the controls. To emphasize the point: it is naive to exclude enforcement problems from a model of environmental control."28)

2.5.2 Economic incentives

Ever since Pigou's pioneering work on technological external effects, economists have discussed whether or not a social optimum could be attained by levying a tax on the residuals discharger (with or without compensation to the damaged party). It has, however, been demonstrated that in the absence of bargaining between the parties involved, either a charge on effluents or a payment (bribe) to reduce discharges will serve to induce the minimum cost combination of discharge reductions in a region. When payments are tied to reductions of discharges they are (at least when entry is excluded) equivalent to charges from an allocative point of view.29)

In practice, however, the authorities use payments to subsidize directly or indirectly the costs of different residuals treatment measures. Indirect cost subsidies are generally achieved by linking favorable tax treatment to certain kinds of residuals treatment activities. Direct subsidies consist of cash payments to various economic agents to reimburse them for some part of their emission control costs. Even though cost subsidies might have some beneficial effects on the income distribution, by distorting the economic incentives faced by dischargers,

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28) Dorfman, R.,"Modelling Through", Interfaces, Vol. 3, No. 4, August 1973, p. 5.

29) Entry for the purpose of collecting the payments not to discharge residuals could be avoided if only existing firms have the legal right to discharge residuals. New firms would then have to purchase these rights if they wanted to enter the industry.

they are likely to increase the total economic burden of a given reduction of discharges.

A basic prerequisite for an optimal use of a system of effluent charges is, as pointed out above, knowledge of the aggregate damage function. In such a case, the authorities would establish a charge equal to the marginal damage for each unit of residual. The producers would then reduce their residuals discharges as long as the marginal cost of doing so was lower than the charge. By this process, the sum of the treatment costs of all dischargers would be minimized since each discharger would be equating his marginal cost to the common charge. The establishment of a charge will have the effect of inducing dischargers (and consumers) to choose the least-cost combination of the first three technological options for environmental quality control. Thus, in the case of linear total damage functions the authorities are able to attain the optimum level of environmental quality without knowing the shape of the treatment cost function.

In the more realistic case where damage functions are not known and the policy objective is to meet specified environmental quality standards, residuals charges can still be used, provided the aggregate treatment cost function is known. Even in this case, the use of residuals charges requires less information than the amount necessary for an optimal use of discharge standards. However, if the aggregate treatment cost function cannot be determined without information about individual treatment cost functions, this policy measure will obviously have no advantage as far as informational requirements are concerned.

In this context it should also be noted that the effluent charges necessary to achieve a given environmental quality standard could, in principle, be determined by a "trial-and-error" process. The basic constraint is that the initial charge would have to be relatively correct in order to induce the least-cost solution. Any major error in the initial charge would be built into subsequent investment decisions involving durable plant and equipment, as well as any further adjustments.

The basic conclusion to be drawn from this discussion of different environmental policy measures is that in the absence of sufficient information, the use of discharge standards will probably ensure that the desired environmental quality level is attained but only at a cost higher than minimum whereas the use of residuals charges will ensure that the level of environmental quality actually achieved (which is not necessarily the desired level) is achieved at minimum total costs.

It should be noted, however, that from certain points of view, residuals charges will always have some advantages in comparison with effluent standards. One of these advantages is the fact that charges provide the residuals dischargers with strong (and continuous) incentives to develop and employ cost-reducing techniques of residuals management. Another important aspect of residuals charges is the fact that the charges provide the government with revenue in a way that does not have the negative effects on the allocation of resources characteristic of most other taxes.30)

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30) For a general discussion of the allocative effects of different types of taxes, see for example Musgrave, R.A., Theory of Public Finance. New York, 1959.

APPENDIX to Chapter 2

CLASSIFICATION OF ENVIRONMENTAL CONTROL MEASURES

10000 MEASURES FOR IMPROVING WATER QUALITY

In-plant control measures to reduce the generation of waterborne residuals

11000	Engineering design considerations
11100	Installation of separate drainage systems
11200	Segregation and collection of specific wastes
11300	Use of surface condensers in place of barometric condensers
11400	Emergency storage facilities
11500	Use of pumps and valves with special seals to minimize losses
11900	Not defined above

12000	Process design modifications
12100	Use of reaction chemicals or feed stocks producing min. residuals
12200	Use of continuous in place of batch processes
12300	Chemical regeneration
12400	Downgraded use of chemicals
12500	Countercurrent use of chemicals and/or washwaters
12600	Elimination of air blowing and water washing
12700	Change in design basis for chemical recovery facilities
12800	Modifying operating conditions
12900	Not defined above

13000	Recovery and utilization of residuals
13100	Recovery of material for reuse in process
13200	Downgraded use of spent chemicals in other processes
13300	Use of sale of residuals as raw material for other processes
13400	Recycling or reuse of water
13500	Heat recovery
13900	Not defined above

14000	Local pretreatment or disposal
14100	Local separators and traps
14200	Evaporation and incineration of noxious liquid residuals
14300	Use of emulsion prevention chemicals
14900	Not defined above
15000	Operation control
15100	Use of automatic in place of manual process controls
15200	Control of production to minimize losses
15300	Administrative control of discharges of waterborne residuals
15400	Monitoring waterborne residuals
15500	Clean-up programs
15600	Employee training
15900	Not defined above

MEASURES TO REDUCE DISCHARGES OF WATERBORNE RESIDUALS

16000	Transportation of waterborne residuals to treatment facilities
16100	Transportation to private facilities
16200	Transportation to public facilities
16300	Transportation to collective facilities
16400	Contract disposal
16500	Transportation to recipient with higher assimilative capacity
16900	Not defined above
17000	Unit operations for collection of waterborne residuals
17100	Mechanical treatment
17110	
17120	Screening (incl. barscreening)
17130	Filtration
17140	Mechanical flocculation
17150	Aeration
17160	Gravimetric separation
17170	Flotation
17180	Centrifugation
17190	Not defined above

17200	Biological treatment
17210	Activated sludge process
17220	Trickling filter
17230	Aerated lagoon
17240	Anaerobic contact
17250	Anaerobic lagoon
17260	Denitrification process
17290	Not defined above

17300	Chemical treatment
17310	Neutralization
17320	Precipitation
17330	Chemical flocculation
17340	Reduction
17350	Oxidation
17360	Disinfection
17370	Nutrient addition
17380	Odor control
17390	Not defined above

17400	Temperature change processes
17410	Temperature control
17420	Evaporation
17430	Freezing
17440	Distillation
17450	Wet oxidation
17460	Combustion
17490	Not defined above

17500	Other methods for collection of waterborne residuals
17510	Absorption
17520	Adsorption
17530	Electrolysis
17540	Ion exchange
17550	Extraction
17560	Dialysis and reverse osmosis
17570	Foaming
17580	Electrochemical treatment
17590	Not defined above

MEASURES TO REDUCE CONCENTRATION OF WATERBORNE RESIDUALS AT RECEPTOR SITES

18000	Measures for handling and disposal of sludge and treated water
18100	Dewatering of sludge
18110	Thickening
18120	Filtration
18130	Vacuum filtration
18140	Pressing
18150	Lagooning
18160	Drying bed
18170	Centrifugation
18190	Not defined above
18200	Stabilization of sludge
18210	Aerobic stabilization
18220	Anaerobic digestion
18230	Chemical stabilization
18240	Thermic stabilization
18250	Composting
18290	Not defined above
18300	Thermic treatment of sludge
18310	Drying
18320	Freezing
18330	Combustion
18390	Not defined above
18400	Disposal of sludge
18410	Land disposal
18420	Sea disposal
18430	Reuse
18490	Not defined above
18500	Disposal of treated water
18510	Controlling the timing of discharges
18520	Surface storage and evaporation

18530	Deepwell disposal
18540	Surface (spray) irrigation
18550	Ocean disposal
18560	Surface discharge
18590	Not defined above
19000	MEASURES TO INCREASE THE ASSIMILATIVE CAPACITY OF RECIPIENTS
19100	Low-flow augmentation
19200	In-stream aeration
19300	Destratification (mixing)
19900	Not defined above
20000	MEASURES FOR IMPROVING AIR QUALITY

<u>In-plant control measures to reduce the generation of airborne residuals</u>

21000	Engineering design considerations
21100	Installation of facilities for segregation and collection of spec. residuals
21200	Installation of emergency storage facilities
21300	Use of sealed pumps and valves to minimize leakage
21900	Not defined above
22000	Process design modifications
22100	Use of reaction chemicals and feed stocks generating min. residuals
22200	Use of continuous processes
22300	Change in design basis for chemical recovery facilities
22400	Modifying operating conditions
22900	Not defined above
23000	Recovery and utilization of residuals
23100	Recovery of materials for reuse in process
23200	Downgraded use of spent chemicals in other processes
23300	Use or sale of residuals as raw materials for other processes

23400	Heat recovery
23900	Not defined above
24000	Operation control
24100	Automatic vs manual process control
24200	Control of production to minimize losses
24300	Administrative control of discharges of airborne residuals
24400	Monitoring airborne residuals
24500	Clean-up programs (dust-removal or dust-binding)
24600	Employee-training
24900	Not defined above

Control measures to reduce discharges of airborne residuals

25000	Unit operations for collection of airborne residuals (P)
25100	Collection of residuals by force of gravity of inertia
25110	Use of baffled chambers
25120	Use of gridcollectors
25130	Use of dry inertial cyclones
25190	Use of other kind of inertial collectors
25200	Collection of residuals by filters (P, G & A)
25210	Use of filters with fabrics
25220	Use of filters with fibrous beds (mineral wool)
25230	Use of filters with granular beds (silicon or chamotte)
25290	Use of filters with other kinds of filtermedia
25300	Collection of residuals by electrostatic precipitators (P)
25310	Use of dry electrostatic precipitators
25311	Plate type
25312	Pipe type
25320	Use of wet electrostatic precipitators
25390	Use of other kinds of electrostatic precipitators
25400	Absorption of residuals by dispersed liquids or gases (P & G)
25410	Absorption by liquid films
25411	Use of packed towers
25412	Use of wetted wall towers

25420	Absorption by liquid drops
25421	Use of spraytowers (incl. cyclone spray chambers)
25422	Use of high velocity scrubbers (incl. venturiscrubber)
25490	Other kinds of absorption
25500	Incineration (G)
25510	Direct thermal combustion (flame)
25520	Catalytic combustion (flame)
25530	Catalytic reduction
25600	Collection of residuals by adsorbers (G)
25700	Other treatment methods for airborne residuals (G & A)
25710	Condensation
25711	Direct
25712	Indirect (condensation-batteries)
25720	Acoustic treatment
25730	Ozone treatment
25740	Injection of counterodorants
25750	Odor masking
25790	Not defined above

MEASURES TO REDUCE CONCENTRATION OF AIRBORNE RESIDUALS AT RECEPTOR SITES

26000	Measures to facilitate dispersion of emitted airborne residuals
26100	Increasing height of stacks
26200	Locating stacks at meteorologically and topographically favorable points
26300	Restricting emissions to meteorologically favorable times (see 21200)
26400	Increasing temperature of stack gases
26500	Increasing velocity of stack gases
26900	Not defined above

<u>Key to abbreviations:</u>

P = Particulates
G = Gases
A = Aerosols

CHAPTER 3

PRINCIPLES FOR OPTIMIZATION OF THE LEVEL OF EMISSION CONTROL

In Chapter 2 it was pointed out that the optimal level of environmental quality was reached when the marginal costs of an additional improvement were equal to the marginal benefits. A continuation of the emission control efforts beyond that level would add more to the costs of treatment than it would reduce damage (= increase benefits), and would therefore reduce total welfare.

The simple diagram presented in section 2.3.2.1 (Figure 2:2) was based on the simplifying assumption that there was only one harmful residual being discharged to the environment (or that all different types of residuals could be given weights and expressed in a common unit), and that the damage associated with these discharges depended only on the concentrations of this residual in the environment. It was also assumed that the effects (damage) of various concentrations of this residual were known and that it was possible to place monetary values on these effects.

The problem of finding the optimal degree of emission control is illustrated in a slightly different way in Figure 3:1.1)

The curve sloping upward to the right illustrates the (hypothetical) relationship between the concentration of the residual in the environment and the monetary value of the associated damage. A movement to the right along the horizontal axis represents increasing concentrations of the residual and increasing monetary damage. The curve sloping upward to the left represents the total costs of improving environmental quality (reducing the concentration of the residual).

The optimal level of emission control is that which minimizes the <u>total</u> costs of residuals disposal.2) The total costs of residuals

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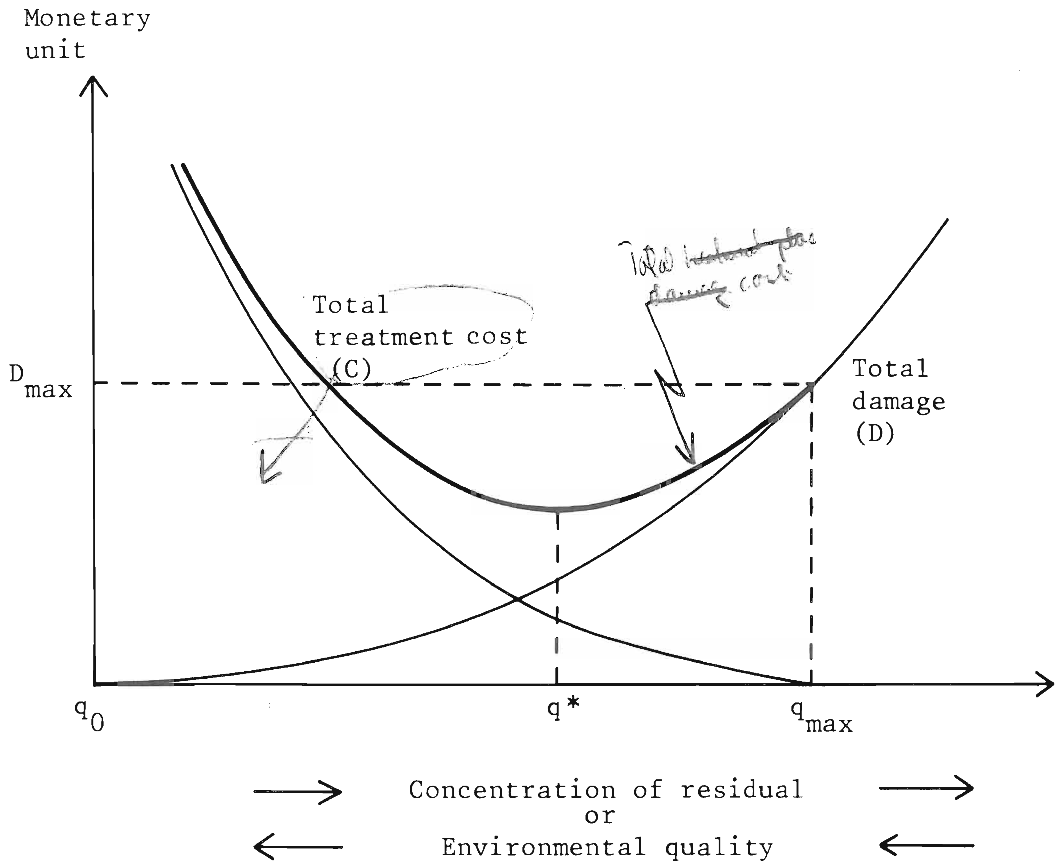
1) For a more complete discussion of this model see: Freeman,III,H.M., Haveman, R.H. & Kneese, A.V., <u>The Economics of Environmental Policy</u>. New York, 1973, pp. 80 ff.

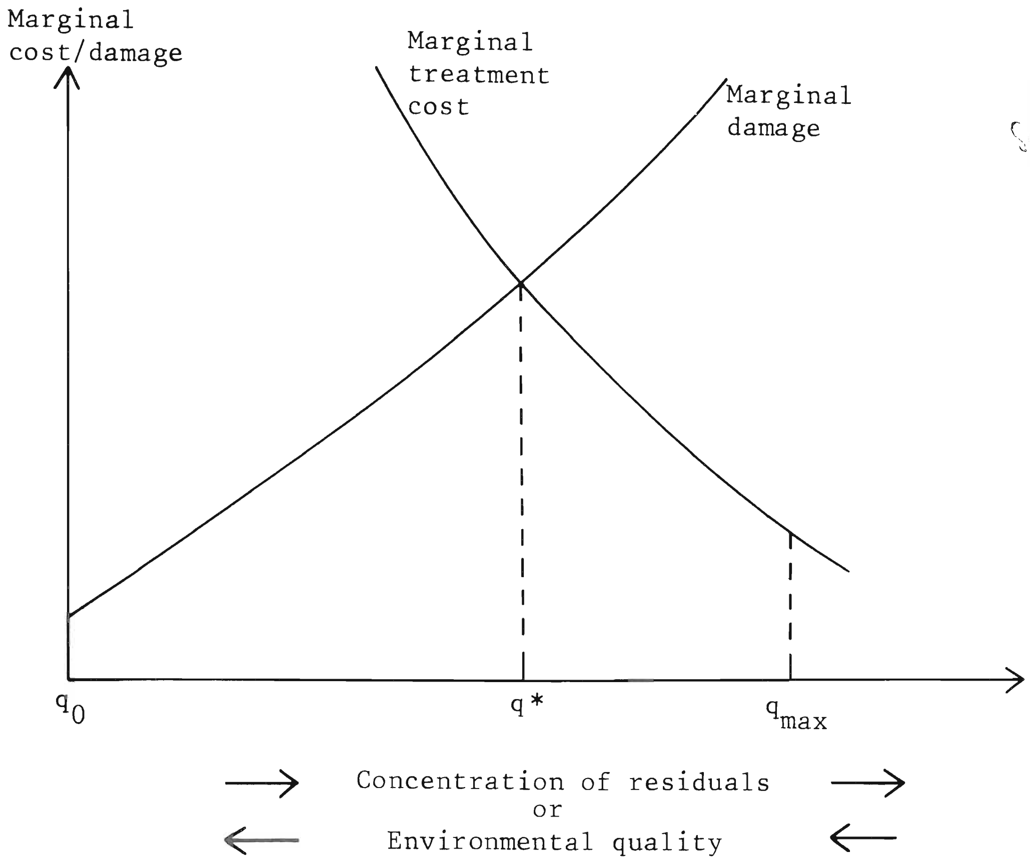
2) Since residual treatment processes only transform the residuals into forms hopefully less damaging to the environment, treatment costs should include costs of possible further treatment and final disposal.

Figure 3:1. Damage and treatment costs for alternative concentrations of residuals



disposal is the sum of monetary damage and treatment costs (D+C) and is shown by the heavy line in Figure 3:1. This total cost curve has its minimum at environmental quality level q*, and this is consequently the optimum level of environmental quality. The problem of finding the optimal degree of emission control could, of course, also be illustrated by a diagram with the corresponding marginal cost and damage functions. Such a diagram, which is presented in Figure 3:2, is similar to the one used in Chapter 2 - the only difference being that an improvement in environmental quality is illustrated by a movement in the oppsosite direction along the horizontal axis and that Figure 3:2 therefore is the mirror image of Figure 2:2.

Figure 3:2. Marginal damage and marginal treatment costs for alternative concentrations of residuals



Spegelvända

3.1 DATA REQUIREMENTS FOR OPTIMIZATION OF EMISSION CONTROL LEVELS

In the discussion above, the optimum control policy was described in terms of the level of environmental quality expressed as a concentration of residuals in the environment. The optimality criterion implied that the value of reductions in the concentration of residuals (= the value of reduction of damage) should be equal to the costs of achieving these reductions. If the authorities were to use regulative measures to ensure the desired reduction in the concentration of residuals, however, it would be necessary to restate the optimality criterion in terms of rates of discharge of the residual. As pointed out already in Chapter 2, however, such a "translation" is quite complicated since the relationships between rates of discharge of residuals and the resulting concentrations of the residuals in the environment depend upon a number of environmental parameters many of which vary randomly over time.

Thus, in order to be able to use this model for environmental quality management, the decision-maker must be able to obtain three kinds of information. First, he must be able to determine the relationships between reductions in residuals discharges and treatment costs. The second piece of required information is the relationship between discharges and environmental quality referred to above. Both pieces of information are necessary in order for the decision-maker to determine treatment costs as a function of the environmental quality level. The final piece of required information is, of course, the relationship between the concentration of residuals and the associated monetary damage.

Needless to say, both the gathering and analysis of the kind of data described above are faced with large difficulties. The most difficult task is to determine the damage function since this involves estimation of the monetary value of services that do not pass through markets and, consequently, do not have prices recorded for them. However, the lack of knowledge of the damage function does not exclude the possibility of using the model described above. It should be pointed out, though, that the use of environmental quality standards (determined on technical and/or political grounds) implies a monetary evaluation of different environmental quality levels.

Another extremely difficult task is, as was pointed out above, to determine the relationships between discharges and concentrations of residuals in the environment. In fact, such relationships are known only for a few forms of residuals. Thus, the decision to limit the present study to a collection and analysis of data on costs of specific discharge reductions must be viewed against the formidable difficulties associated with collection (and analysis) of data on ecological relationships and monetary damage. The primary objective of the present study is therefore to try to obtain treatment cost data in such a form that it could be used in the type of model described above.

3.2 THE PROBLEM OF AGGREGATION

In the emission control model presented above it was assumed that there was only one residual (or that different residuals could be weighted and expressed in some common unit) and that we could identify the relationship between reductions in the concentration of that residual in the environment and treatment costs. The lack of data on the relationships between the rate of discharge of residuals and the concentration of residuals in the environment (i.e. on environmental transformation functions) motivated the present study to limit itself to an investigation of the costs of specific reductions of discharges. This limitation of the scope of the study did not, however, eliminate the problems associated with the high level of aggregation implied by the model described above.

One of these problems originates in the fact that most production processes generate more than one residual. As pointed out above, the damage associated with discharges of the different residuals is generally not known in detail. All we know is that damage differs sufficiently to make it impossible simply to add the various residuals. Thus, in order for the authorities to be able to determine the objective for their emission control policy, weights have to be attached to the different residuals.3) That such a weighting procedure actually takes place (explicitly or implicitly) is reflected in the fact that emission standards generally do differ between residuals. Needless to say, the choice of weights reflects the decision-maker's views on the relative damage associated with each residual. Since the environment's assimilative capacity generally differs between regions, the decision-maker would have to use different sets of weights for different regions.

In view of the difficulties of finding the "correct" sets of weights, a question of importance to the present study is to what extent it is possible to avoid this problem by an appropriate choice of the level of aggregation for the analysis. If the analysis was conducted at the plant level, obtainable cost data would in most cases refer to reductions of discharges of more than one residual. Without a set of weights it would be impossible to determine the treatment costs per kg of discharge reduction - the relevant cost concept for the type of model discussed above. This problem can be partly overcome by an analysis at a further disaggregated level. Thus, if the

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3) In his theoretical study in environmental economics, K.-G. Mäler assumes that the decision-maker (the environmental protection agency) has determined the prices on all environmental services (including the prices on residuals disposal). Mäler points out, however, that "in order to make sense, the prices on residuals must in some way reflect the damages to the environment they can cause". See Mäler, K.-G., A Study in Environmental Economics. (Ph.D. dissertation, University of Stockholm). Stockholm 1972.

production process at individual plants is broken down into its components (i.e. into its various sub-processes), our possibilities to determine the treatment costs for specific residuals will increase substantially. This is mainly due to the fact that at the sub-process level of analysis, the assumption that there is only one residual generated is far more realistic. Needless to say, there are many sub-processes which generate more than one residual. In many cases, however, treatment measures applied at the sub-process level are designed to reduce the discharges of one particular residual which means, in turn, that the problem of joint cost allocation does not arise. In those cases where treatment measures reduce discharges of several residuals simultaneously, some weighting procedure will still be necessary in order to allocate the joint costs.

Thus, the choice of the level of aggregation for the present study was motivated by the necessity to have the treatment cost data expressed in terms of annual costs per kg of discharge reduction. In the absence of an appropriate set of weights for different residuals, the best level of aggregation was found to be the sub-process level rather than the plant level.

3.3 COST CONCEPTS

3.3.1 The social costs of emission control measures

As pointed out in Chapter 2, the relevant cost concept for decisions pertaining to the allocation of resources is social cost. The concept of social cost expresses the cost to society of any particular commitment of resources in terms of the benefits of the most productive alternative use of these resources. Even if the concept of social cost is well defined from a theoretical point of view, however, the practical problems of estimating social costs are immense.

In standard welfare theory it is shown that the conditions under which private costs will coincide with social costs are those of competitive equilibrium. The long string of assumptions usually made in such standard theory includes assumptions of absence of indivisibilities as well as technological external effects.

In earlier economic literature, externalities were, as pointed out in the preceding chapter, mostly regarded as exceptional and relatively insignificant anomalies in economies characterized by an otherwise optimal allocation of resources. The more recent contributions to economic theory in this field have, in contrast, taken the view that for economies characterized by large (and growing) flows of materials and energy, and for which the recipients of the flows of residual materials and energy are common property resources, externalities must be regarded as rather pervasive phenomena.

When the private costs of some proposed use of resources do not reflect the opportunity costs to society, these social costs have to be estimated some way or another. The most common method of estimating the social costs of an environmental control measure is to collect data on the resulting private costs in the various sectors affected and then assume that the sum of these partial cost estimates constitutes a good approximation of the "true" social costs. In such exercises, however, it is implicitly assumed that factor prices adequately reflect the factors' social costs. The well documented existence of market imperfections, factor underemployment, indivisibilities, etc. makes such an assumption quite unrealistic. Thus, estimates of social costs made in this manner will generally be not only partial but also quite rough. Consequently, questions concerning the efficiency of alternative environmental control measures generally cannot be answered in a fully satisfactory way by such cost estimates. This does not mean, however, that such estimates have no value at all but rather that their value depends upon the use to which they are put.

3.3.2 The concept of annualized cost

To an individual firm, the costs of an environmental control measure should ideally be measured as the difference between the present value of the production cost flows with or without the control measure (ceteris paribus). However, the practical difficulties of obtaining adequate data for such calculations make it necessary to use other methods.

Characteristic of most environmental control measures is that they require substantial capital expenditures. Capital expenditures for the purpose of reducing residuals discharges include all traditional expenditures such as design; purchase of land, equipment, and materials; site preparation; construction and installation; plus any additional expenditures identified as being required to bring the chosen treatment technology into operation (including expenditures to arrange related necessary secondary residuals disposal). Capital expenditures for subsequent major modifications (excluding "normal" maintenance and repair), and any losses due to down time (i.e. production halts required to install emission control equipment) should also be included.[4)]

When control measures take the form of installation of treatment equipment of the "add-on" type, one can fairly well identify the capital expenditures. However, the measures will, as mentioned above, sometimes take the form of process changes. In such cases, it is generally quite difficult to identify the part of the total capital expenditures for the process change that refers to emission control.[5)]

In order to fit into the model presented above (and to allow comparisons with other cost items in the firm's accounting), estimates of the costs of discharge reductions should be presented in annualized form. The concept of annualized costs will include two main categories of costs, namely:

[4)] The financial burden of the initial capital expenditures may be reduced by direct government subsidies or by tax measures such as special investment credits or depreciation allowances. Credits of this type should be identified separately, since they represent a shifting of the burden of initial capital expenditures from the private to the public sector rather than a reduction of the total burden to society.

Furthermore, in order to be able to estimate the new capital expenditures that would be necessary for any required reduction of emissions, empirical data on the initial capital expenditures for emission control equipment purchased in different years need to be adjusted for changes in equipment price levels from the date of acquisition to a uniform date.

[5)] One approach to this problem would be to try to estimate the "additional costs" of the capital expenditures incurred in order to reduce the generation and discharge of residuals. In this context it becomes necessary to decide what type of investment to choose as a basis for comparison so that these additional costs could be calculated. Since regulations concerning discharges of residuals generally have been in existence for some time, some costs would have been incurred anyway - just as a continuation of previous practice. Some cost, however, will be incurred as a result of new discharge regulations. If this distinction is made, the basis for comparison in assessing the emission control costs associated with a process-integrated control measure would be the capital expenditures for the production technology complying with previous emission standards.

In assessing the additional costs, adjustments would also have to be made for capacity increases and product quality changes that might follow from the capital expenditures.

(a) Capital costs, and

(b) Operating and maintenance costs.

Capital costs consist of financial charges computed as the opportunity cost of capital (interest rate) times the amount of capital employed for purposes of emission control, plus depreciation charges computed to reflect the rate at which the stock of capital is used up over its life-time.

When depreciation charges are computed, the life-time of equipment should be calculated on the basis of economic rather than technical considerations. The conomic life-time of equipment is generally shorter than the physical life-time because of obsolescence and the risk of reduced future demand for certain facilities. The shorter write-off time sometimes allowed for tax purposes affects the tax cost of capital, but not the depreciation charges relevant for cost accounting purposes. Thus, since the objective is to identify the rate of consumption of capital, the depreciation rate for tax purposes should not be used. Among the more important factors influencing the plant manager's choice of depreciation rate are the expected rate of technological development and the remaining economic life-time of the plant.

In order to be able to estimate the effects on product prices of emission control costs, the opportunity cost of capital should ideally reflect all factors likely to affect selling prices.6) Since borrowed capital is available (at a certain interest rate) only because equity capital tends to guarantee its repayment, the opportunity cost of capital must include provisions for interest on borrowed capital, profit on the equity capital, and an amount to cover taxes on the profit on equity, in proportion to the amount of borrowed and equity capital used. In general, if a company does not expect to recover all of

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6) In this context it should be pointed out that emission control equipment already in existence can be regarded as "sunk". Assuming that existing environmental regulations (e.g. emission standards) leave the plants with a choice only between (a) operating the plant with the control equipment and (b) closing the plant, and that the control equipment has no alternative use (i.e. disregarding the possible sale or scrap value), the opportunity cost of this capital is zero. Existing plants will, therefore, continue operations as long as total operating costs (including, of course, operating costs of emission control equipment) are covered. Thus, the decisions of existing plants regarding the supply of goods the production of which is affected by environmental regulations will not be influenced by capital costs of existing emission control equipment. Capital costs are relevant only in situations where the decision regarding the use of available funds had not yet been made.

these items in addition to depreciation, it will not invest the capital. This is not to say, however, that expectations are always fulfilled.

The opportunity cost of capital may differ among countries as well as among industry branches due to differences in availability of capital, risk, market structure, taxes, and other factors. Since the (ex post) return to capital in any one company or industry rarely reflects the return achievable from alternative uses, it is very difficult to establish the "true" opportunity cost. One way to handle this problem is to use the weighted average cost of interest, income taxes, and profit for all companies in an industry.

The tax cost of capital employed for emission control purposes may in some cases be reduced as compared with the average tax cost of profit on equity, by the allowance of more rapid depreciation for such equipment than for other equipment. In such a case, the annual tax reduction should be considered as an offset to the tax cost of capital. Other reductions in capital costs may include low interest loans by the government or government guarantees that result in lower interest rates, etc. As with investment subsidies that reduce initial capital expenditures, tax reductions or financial aid in connection with emission control expenditures should be identified separately because they tend to reduce private costs (and, depending upon cost accounting practices, possibly also prices) but not social costs.7)

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7) In the case of non-permanent schemes of subsidization of emission control investments, it could be argued that firms should regard such subsidies as windfall gains not to be considered in the computation of annual depreciation charges for cost accounting purposes. The motivation for this is the argument that depreciation charges should be calculated to reflect the rate at which the stock of capital is used up rather than the way in which it was financed. Under the assumption that firms intend to stay in business, they will have to provide funds for the replacement of their residuals treatment equipment. If the firms have calculated their depreciation charges on the original investment costs minus subsidies, they will not be able to finance the replacement investments out of their depreciation reserves (excluding all problems associated with inflation and technological development). Such an accounting practice would tend to understate the annualized costs of emission control and imply a certain degree of "capital consumption".

In spite of the obvious "incorrectness" of such an accounting practice it is commonly used by Swedish firms. The reason for this practice seems to be the fact that firms have to follow this principle in their statements to the fiscal authorities and that they therefore find it awkward to use another principle in their cost accounting. The fact that firms do not use both principles could also be interpreted as an indication of a relative insignificance of emission control costs.

The second item of the annualized costs of emission control measures consists of all costs associated with operating and maintaining emission control equipment. These costs include expenditures on labor, materials, energy, insurance, taxes, disposal of solid residuals, etc. and they should as far as possible be accounted for net of any revenues that might result from the operation of emission control equipment.

Maintenance costs are defined as the expenditures required to sustain the operation of a control device at its designed efficiency. This is generally best accomplished with a scheduled maintenance program and proper replacement of defective and worn parts. The maintenance costs must be estimated on the basis of existing knowledge and understanding of control system applications, and should be expressed as average annual values computed over the useful life of the equipment. Such a procedure is of course somewhat artificial since, in actual life, maintenance costs will increase with the age and wear of the equipment.

In order for these cost estimates to be of any help to the decision-maker, they should, at least in an approximate way, reflect the future costs of reducing discharges. One way to arrive at such cost estimates is to (1) study actual costs in the past, (2) establish standard cost functions for reduction of various types of discharges, (3) make assumptions about future production volumes and amounts of residuals generated, and (4) apply the cost functions to the projected amounts of residuals to determine the costs of a specified level of treatment. Such extrapolations must be regarded with some scepticism since there are good reasons to believe that technological changes will alter significantly not only the amounts of residuals generated per ton of product but also the costs of reducing particular forms of discharges.

The estimation of standard cost functions for reduction of discharges of various kinds of residuals is complicated by the fact that the longer the time-perspective the higher the number of available alternatives to accomplish a reduction of discharges. The costs of reducing discharges might, for example, be lowered substantially by changes in the production process itself. Changes in the production process will, however, depend not only on public environmental control policies but also on changes in processing technology, changes in relative prices of inputs and in input qualities, changes in relative prices of output and in output quality requirements, etc. The shorter the expected remaining life-time of its equipment, the smaller the probability that a firm will choose to combine the equipment with residuals treatment capital of the "add-on" type. Thus, in order to be able to make accurate estimates of the long-run costs of discharge reductions for a firm (or an industry) one has to know the expected economic life-time of its equipment under various environmental quality standards/emission standards. It goes without saying that such information is not easily obtained.

An extension of the time-perspective also raises the question whether or not future costs of reducing discharges will be lowered further by the development of better process technology and/or even more efficient methods for treating and recycling residuals. The time necessary for developing, testing, and marketing new processing technology generally amounts to something between ten and fifteen years. In a somewhat shorter perspective, technological changes will mainly consist of various modifications of and/or additions to existing processing and treatment equipment. Thus, if the time horizon for the cost estimates is limited to the medium-run, it is possible (at least within reasonable margins of error) to predict which methods of processing and residuals treatment will be in common use.

3.4 METHODOLOGY OF THE STUDY

Since the costs of reducing discharges generally vary not only between the different sub-processes of a production process but also between the different technologies available for these sub-processes, it is, as pointed out above, necessary to disaggregate the production processes into their respective processing steps. The estimation of standard treatment-cost functions is, therefore, carried out in the following way:

(a) identification of the processing steps associated with the production of each good;

(b) estimation of the "raw residual loads" generated at different levels of operation of these processing plants;

(c) identification of each distinct control and treatment technology, including both in-plant and end-of-process technologies, which are capable of being applied;

(d) determination of the discharge levels resulting from the application of each of the treatment and control technologies, and finally,

(e) estimation of the minumum costs of reducing discharges to specified levels.

At the time when the present project was initiated (i.e. January, 1971), no study using the same kind of approach had yet been published and it was therefore necessary to start by developing the proper analytical tools. The first step was to construct a classification scheme of the production processes which would allow a systematic analysis of emission control measures at the appropriate level of disaggregation.

The starting point for this classification scheme (and accompanying set of code numbers) was the six-digit SNI (Swedish Classification of Industry) code. The first four digits of this code are identical with the ISIC (International Standard for Industrial Classification) code and the last two digits are used for a national classification of the main categories of manufacturing processes within the major activities.

The disaggregation of the production process was carried out basically along operational lines. Thus, the production processes were divided into a number of sub-processes where each sub-process was defined by the type of physical change of the raw materials (or intermediate products). For example, the process of steel production was disaggregated into raw materials agglomeration (sintering), reduction (blast furnace operations), desulphurization, and refining (raw steel manufacturing). In order to enable a study of the various supplementary processes generally found at most industrial plants, the classification system was made big enough to accomodate up to 99 sub-processes. Thus, the first two digits of the six-digit code developed were used to designate sub-processes.

For each sub-process there are, in general, several alternative technologies available. Some of these technologies have very different characteristics as far as the generation of residuals is concerned. The fact that a change of process technology in some cases might constitute the best emission control measures made it necessary to design the classification scheme so as to enable an identification of different sub-process technologies. By letting the third and fourth digits represent processing technology, the scheme was made big enough to enable the inclusion of no less than 99 technologies of each sub-process.

The last two digits of the code were used in those cases where a sub-process under study consisted of several different operations, of which only a few were important from the viewpoint of residuals management. The manufacturing of coke (which is sometimes a sub-process at an integrated steel mill) can be taken as an example. In the by-product coking process there are five major operations (apart from the numerous operations associated with the recovery of chemicals), namely: coal handling, charging, coking, pushing, and quenching. Any meningful analysis of emission control in connection with the coking process will have to consider these operations separately.

The classification scheme, which was developed in close co-operation with industry experts, proved to be extremely helpful during the data collection phase of the study. By combining this scheme with the classification scheme for residuals treatment processes (see appendix to chapter 2) it was possible to bring some order into the apparent chaos of the data used for the study and to describe the production and treatment processes of the studied plants quite accurately by vectors of code numbers. These vectors were then used as a starting point for residuals matrices where the quantities of the residuals generated in the sub-processes (or operations) were registered as positive entries in the columns for the respective residual category, and the quantities of residuals treated by some kind of treatment process as negative entries in some columns and as positive in others (due to the fact that residual treatment does not "annihilate" the residual but rather changes it into a form hopefully somewhat less harmful to the environment). By comparing, for each kind of residual, the amounts generated with the amounts discharged, it was possible to get a fairly accurate picture of the effects on emissions of different control measures. A schematic illustration of the format used for organizing the data is found in Table 3:1.

The classification systems for the iron & steel and pulp & paper industries are presented in appendices to this chapter.

3.5 CHARACTERISTICS OF THE DATA USED IN THE PRESENT STUDY

Simultaneously with the Environment Protection Act - which came into force on July 1, 1969 - a subsidization scheme was set up as an incentive for plants already in operation at that date to speed up the

Table 3:1. A schematic illustration of the format used for organizing the data

Sub-process	Production capacity	Treatment process	Gas or water flow	Amount treated	Waterborne residuals			Airborne residuals			Solid residuals			Capital expenditures	Subsidies	Capital costs	Operating costs	Total annual costs
					Generated	Reduced	Dis-charged	Generated	Reduced	Dis-charged	Generated	Reduced	Dis-charged					
Code	Tons/ year	Code	(m^3/h)	kg/ hour	kg/ hour	kg/ hour	kg/ hour	kg/ hour	kg/ hour	kg/ hour	kg/ hour	kg/ hour	kg/ hour	10^3 S.Cr.	10^3 S.Cr.	10^3 S.Cr.	10^3 S.Cr.	10^3 S.Cr.
P_1	700							A_{11} A_{12}										
		T_{11}	500	A_{11}					$A_{11}-a_{11}$	a_{11}	$A_{11}-a_{11}$			K_{11}	b_{11}	C_{k11}	C_{o11}	$C_{k11}+C_{o11}$
P_2	900				W_{21} W_{22}													
		T_{21}	700	W_{21} W_{22}		$W_{21}-w_{21}$ $W_{22}-w_{22}$	w_{21} w_{22}				$W_{21}-w_{21}$ $W_{22}-w_{22}$			K_{21}	b_{21}	C_{k21}	C_{o21}	$C_{k21}+C_{o21}$
⋮																		
		⋮																
⋮																		
		⋮																
⋮																		
		⋮																
⋮																		
		⋮																
P_n																		
		T_{nl}												K_{nl}	b_{nl}	C_{knl}	C_{onl}	$C_{knl}+C_{onl}$
Σ																		

[illegible]

ex post · [illegible] av subventionerna. bias uppåt eller nedåt:

[illegible] bias i dessa uppgifter. ~~[illegible]~~

investments necessary for compliance with the Act. Through the cooperation of the Environment Protection Board - the agency to which firms had to apply for the subsidies - the subsidy applications were made available to the present study. The data covered primarily those emission control investments that were carried out between July 1, 1969 and July 1, 1973 by plants in operation before July 1, 1969. Consequently, the data do not cover all investments for emission control by Swedish industry during the period in question. Since no emission control investments by new plants were entitled to any subsidies, firms had no incentives to supply any information concerning the costs of these measures either in applications to the Franchise Board for a franchise or in applications to the Environment Protection Board for an exemption. Consequently, all emission control investments by new plants were excluded in the present study. Since the number of new plants constructed during this period in the two industries under study were very few, these omissions were hardly important.

[illegible] att [illegible] subventionerna [illegible] fördelning.

A slightly more difficult problem was created by the fact that a number of plants which were in operation before July 1, 1969 expanded their capacity during the period under investigation. The emission control measures undertaken by these plants were, of course, designed to handle the amount of residuals generated by the expanded plants. However, in the directives to the government subsidization scheme, it was stated that emission control measures reducing discharges from new production capacity would not be entitled to any subsidies. The fact that the control measures generally reduced discharges from the old and the new capacity simultaneously, meant that the base on which the Environment Protection Board were to calculate the subsidies, had to be adjusted for capacity changes. This adjustment was accomplished by the help of a simple formula where adjusted capital expenditures were calculated as actual capital expenditures times the square root of the ratio between the old and the new production capacity (which in case of a capacity increase always must be smaller than one).¹⁾

[illegible] cost function [illegible] cost!

Note marginal = incremental.

1918

170 150 $\sqrt{1.5}$

25/kg. 20 kg.

[illegible] underlaget:

Since an additional objective of the present study was to estimate the total reduction of discharges accomplished by the subsidies, it was decided to use the original capacity (and, consequently, the adjusted capital expenditures) as point of reference. Thus, the total capital expenditures for emission control purposes during this period were some-

1)

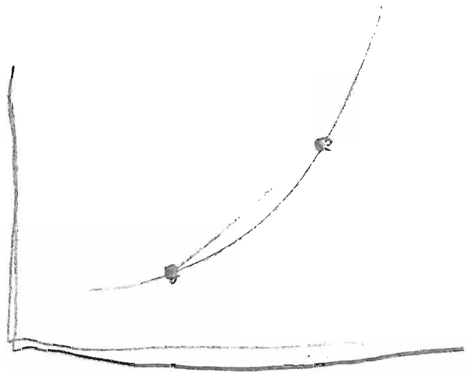
discharge reduction

% mindre

what larger than the figures presented in chapters 5, 6 and 7 would seem to indicate.

For a large part of the emission control measures included in the present study, the only data available were (apart from data on expected discharge reductions) the amount of capital expenditures for the control equipment. Thus, in order to be able to calculate the annual capital costs, it was necessary to choose a depreciation period and an interest rate. In accordance with the so-called SSVL-project (which was a basically technical study of emission control possibilities in the Swedish pulp and paper industry), it was decided to use a 10-year depreciation period and a 10 % interest rate for all kinds of emission control equipment.[8] In order to simplify the calculations, capital costs were calculated as an annuity (corresponding to 0.1627 of capital expenditures).

The fact that subsidies were given in proportion to capital expenditures only, meant that operating costs were not always specified. In those cases where data on operating and maintenance costs of emission control costs were lacking, these cost items were estimated by the help of standard engineering data. Thanks to the fact that the data included information on gas or water flows to be treated, these estimates could be made quite accurate. Most cost items were expressed in the 1972 price level.



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[8] Skogsindustrins Miljövårdsprojekt. Stockholm, 1973.

APPENDIX 1 to Chapter 3

CLASSIFICATION OF PROCESSING STEPS IN IRON AND STEEL PRODUCTION

PRODUCTION OF IRON AND STEEL: 37 10 10

Code			1	2	3
1	2	3	Sub-process	Technique	Operation
01 00 00			Pre-treatment of raw material for the reduction process		
	01 01 00			Pan sintering	
		01 01 01			Handling of ore concentrate
		01 01 02			Mixing
		01 01 03			Baking
		01 01 04			Discharging of pan
		01 01 05			Crushing
		01 01 06			Separation of reject
		01 01 99			Other operation
	01 02 00			Band sintering	
		01 02 01			Handling of ore concentrate
		01 02 02			Mixing
		01 02 03			Sintering
		01 02 04			Cooling
		01 02 05			Crushing
		01 02 06			Separation of reject
		01 02 99			Other operation

Code			1	2	3
1	2	3	Sub-process	Technique	Operation
	01 03 00			Pelletizing	(Band)
		01 03 01			Handling or ore concentrate
		01 03 02			Mixing
		01 03 03			Balling
		01 03 04			Sintering
		01 03 05			Cooling
		01 03 06			Screening
		01 03 99			Other operation
	01 04 00			Pelletizing	(Grate-kiln)
		01 04 01			Handling of ore concentrate
		01 04 02			Mixing
		01 04 03			Balling
		01 04 04			Drying
		01 04 05			Pre-heating
		01 04 06			Sintering
		01 04 07			Cooling
		01 04 08			Screening
		01 04 99			Other operation
	01 05 00			Pelletizing	(Shaft)
		01 05 01			Handling of ore concentrate
		01 05 02			Mixing
		01 05 03			Balling
		01 05 04			Sintering in shaft furnace
		01 05 05			Screening
		01 05 99			Other operation

PRODUCTION OF IRON AND STEEL: 37 10 10

Code			1	2	3
1	2	3	Sub-process	Technique	Operation
	01 97 00			Other sintering technique	
	01 06 00			Cold binding (Autoclave)	
	01 07 00			Cold binding (Intermixing with cement)	
	01 98 00			Other technique for cold binding	
	01 08 00			Screening of lump ore	
	01 99 00			Other technique for pre-treatment of material for the reduction process	
02 00 00			Reduction		
	02 01 00			Blast furnace	
		02 01 01			Tapping of raw iron
	02 02 00			Electrical low-shaft oven	
		02 02 01			Tapping of raw iron
	02 97 00			Other technique for high temperature reduction (Smelting reduction)	
		02 97 01			Tapping of raw iron
	02 03 00			Production of sponge iron in shaftoven	
	02 04 00			Production of sponge iron in rotarykiln	
	02 05 00			Production of sponge iron, fluidized bedding	
	02 06 00			Production of sponge iron	
	02 98 00			Other technique for low-temperature reduction	
	02 99 00			Other technique for reduction	

Code			1	2	3
1	2	3	Sub-process	Technique	Operation
03 00 00			Desulphurization of raw iron		
	03 01 00			Rotary kiln	
	03 02 00			Shaking ladle	
	03 03 00			Injection of slagformer in ladle	
	03 99 00			Other technique for desulphurization of raw iron	
		03 00 01			Tapping of desulphurized raw iron
		03 00 02			Mixing of raw iron
		03 00 03			Production of ingots
04 00 00			Process of manufacturing raw steel		
	04 01 00			LD	
	04 02 00			LD-AC	
	04 03 00			Kaldo	

PRODUCTION OF IRON AND STEEL: 37 10 10

Code			1	2	3
1	2	3	Sub-process	Technique	Operation
	04 04 00			Bottom-blown oxygen converters	
	04 05 00			Thomas	
	04 98 00			Other converting technique	
	04 06 00			Basic Martin without oxygen	
	04 07 00			Basic Martin with oxygen	
	04 08 00			Acid Martin without oxygen	
	04 09 00			Acid Martin with oxygen	
	04 11 00			Basic electric arc furnace	
		04 11 01			Pre-heating of scrap
		04 11 02			Other operation
	04 12 00			Basic electric arc furnace with oxygen	
		04 12 01			Pre-heating of scrap
		04 12 02			Other operation
	14 13 00			Basic electric arc furnace with oxygen and oil	
	04 14 00			High frequency furnace	
	04 15 00			Low frequency furnace	
	04 16 00			Net frequency furnace	
	04 99 00			Other technique for manufacturing of raw steel	
		04 00 01			Tapping of raw steel

PRODUCTION OF IRON AND STEEL: 37 10 10

Code			1	2	3
1	2	3	Sub-process	Technique	Operation
05 00 00			Adjustment		
	05 01 00			Open ladle	
	05 02 00			Covered ladle	
	05 03 00			Ladle furnace type ASEA-SKF	
	05 04 00			Ladle furnace type Finkl-Mohr	
	05 05 00			Ladle furnace typ Witten	
	05 06 00			Only vacuum-treatment by the RH-method	
	05 07 00			Only vacuum-treatment by the DH-method	
	05 08 00			Only vacuum-treatment by the Bockum-method	
	05 09 00			Argon-Oxygen-Decarborization	
	05 10 00			UHB-method	
	05 11 00			Electronbeam furnace	
	05 12 00			ESR-method (Electroslagrefining)	
	05 13 00			VAR (Vacuum arc refining)	
	05 14 00			Furnace with plasmaburner	
	05 99 00			Other technique for adjustment	
		05 00 01			Tapping of refined steel

PRODUCTION OF IRON AND STEEL: 37 10 10

Code			1	2	3
1	2	3	Sub-process	Technique	Operation
06 00 00			Casting		
	06 01 00			Down-hill mould casting	
	06 02 00			Up-hill mould casting	
	06 03 00			Continous casting	
	06 04 00			Pressure casting	
	06 05 00			Desintegration + compactation (ASEA-STORA-method)	
	06 06 00			Centrifugal casting	
	06 99 00			Other casting technique	

PRODUCTION OF IRON AND STEEL: 37 10 10

Code			1	2	3
1	2	3	Sub-process	Technique	Operation
07 00 00			Forming of material		
	07 01 00			Hot rolling	
		07 01 01			Heating
		07 01 02			Rolling
		07 01 03			Water spraying
	07 02 00			Cold rolling with emulsions as cooling and lubricating substance	
	07 03 00			Cold rolling with oil as cooling and lubricating substance	
	07 04 00			Forging	
	07 05 00			Drawing	
	07 06 00			Spraying	
	07 99 00			Other technique for forming of material	
08 00 00			Preparation of surface		
	08 01 00			Grinding	
	08 02 00			Blasting	
	08 03 00			Flame chipping	
	08 04 00			Mechanical descaling	
	08 97 00			Other mechanical preparation of surface	
	08 05 00			Pickling in sulphuric acid	
	08 06 00			Pickling in hydrocloric acid	
	08 07 00			Pickling in phosphoric acid	
	08 08 00			Pickling in hydrofluoric acid	
	08 09 00			Pickling in nitric acid	
	08 10 00			Pickling in oxalic acid	
	08 11 00			Pickling in percloric acid	
	08 12 00			Pickling in sulphonic acid	
	08 13 00			Pickling in mixed acid	

PRODUCTION OF IRON AND STEEL: 37 10 10

	Code		1	2	3
1	2	3	Sub-process	Technique	Operation
	08 14 00			Pickling in water solutions of acid inorganic salts	
	08 15 00			Pickling in organic compounds	
	08 16 00			Pickling in melted caustic soda	
	08 17 00			Pickling in meted caustic potash	
	08 99 00			Other technique for preparation of surface	
09 00 00			Coating		
	09 01 00			Phosfate pre-treatment	
	09 02 00			Coating with copper	
	09 03 00			Coating with lime	
	09 04 00			Treating with borax	
	09 05 00			Lubrication	
	09 99 00			Other coating technique	
10 00 00			Heating in reheating furnace		
	10 01 00			Electrically heated	
	10 02 00			Gas heated	
	10 03 00			Oil heated	
	10 99 00			Other heating technique	
11 00 00			Coking		
		11 00 01			Handling of coal
		11 00 02			Charging
		11 00 03			Burning
		11 00 04			Discharging
		11 00 05			Quenching

PRODUCTION OF IRON AND STEEL: 37 10 10

Code			1	2	3
1	2	3	Sub-process	Technique	Operation
98 00 00			Service		
	98 01 00			Coke handling	
	98 02 00			Limestone handling	
	98 03 00			Dolomite handling	
	98 04 00			Handling of fusing agents	
	98 05 00			Scrap handling	
	98 06 00			Handling of ore concentrate	
	98 07 00			Handling of lump ore	
	98 98 00			Handling of other materials	
	98 08 00			District heating and steamplants	
	98 09 00			Masoning station	
	98 99 00			Other service including maintenance	
99 00 00			Other sub-process		

APPENDIX 2 to Chapter 3

CLASSIFICATION OF PROCESSING STEPS IN PULP AND PAPER PRODUCTION

MANUFACTURE OF MECHANICAL OR SEMI-CHEMICAL PULP: 34 11 11

Code			1	2	3
1	2	3	Sub-process	Technique	Operation
01 00 00			Crosscutting		
	01 01 00			Crosscutting in beam crosscutting saws	
	01 02 00			Crosscutting in slashers	
	01 03 00			Crosscutting in band saws	
02 00 00			Barking		
	02 01 00			Barking in wet barking drums	
	02 02 00			Barking in dry barking drums	
	02 03 00			Barking in parallel barking machines	
	02 04 00			Barking in knife barking machines	
	02 90 00			Barking in other kind of barking machines	
03 00 00			Chipping		
		03 00 01			Chipping (multi-knife chipping machines)
		03 00 02			Aftertreatment in disintegrator
		03 00 03			Chip screening
		03 00 04			Additional screening in disintegrator
		03 00 05			Screening in grit traps
04 00 00			Pretreatment of logs or chips		
	04 01 00			Pretreatment in hot water or steam	
	04 02 00			Pretreatment in neutral sulphite (pH 6-9)	
	04 03 00			Pretreatment in sodium hydrate (Na OH)	
05 00 00			Defibering		
	05 01 00			Grinding	
	05 02 00			Defibering by the Masonite-method	
	05 03 00			Defibering in disk refiners	
	05 04 00			Defibering in conical refiners	

MANUFACTURE OF MECHANICAL OR SEMI-CHEMICAL PULP: 34 11 11

Code			1	2	3
1	2	3	Sub-process	Technique	Operation
06 00 00			Digesting (semi-chemical pulp)		
	06 01 00			Digesting in acid sulphite	
	06 02 00			Digesting in bi-sulphite	
	06 03 00			Digesting in neutral sulphite (batch)	
	06 04 00			Digesting in sodium hydrate (Na OH)	
	06 05 00			Digesting in sulphate	
07 00 00			Coarse screening		
		07 00 01			Coarse screening in knot strainers
		07 00 02			Dewatering
		07 00 03			Coarse screening in separators
		07 00 04			Grinding of reject pulp (knots)
08 00 00			Pulp washing (semi-chemical pulp)		
	08 01 00			Pressing	
	08 02 00			Washing on filters	
	08 03 00			Washing in pulp containers	
	08 04 00			Washing in batch digesters	
	08 05 00			Washing in continuous digesters	
	08 06 00			Washing in continuous diffusers (radial washing)	
	08 07 00			Washing in diffusers	
09 00 00			Fine screening		
		09 00 01			Fine screening in centrifugal screens
		09 00 02			Fine screening in vortex cyclones
		09 00 03			Fine screening of reject pulp
		09 00 04			Grinding of reject pulp (see 07 00 04)
10 00 00			Bleaching (semi-chemical pulp)		
	10 01 00			One stage (natrium- or hydrogen peroxide)	
	10 02 00			Two stage bleaching (peroxide + hydrosulphite)	

MANUFACTURE OF MECHANICAL OR SEMI-CHEMICAL PULP: 34 11 11

Code			1	2	3
1	2	3	Sub-process	Technique	Operation
11 00 00			Pulp thickening		
	11 01 00			Pulp thickening in sieb-cylinder	
	11 02 00			Pulp thickening in cylinder vat machine	
12 00 00			Pulp lifting		
	12 01 00			Pulp lifting in Fourdrinier section	
	12 02 00			Pulp lifting in cylinder vat machine (Kamyr)	
13 00 00			Pressing		
14 00 00			Drying		
	14 01 00			Cylinder drying	
	14 02 00			Hot air drying (fan drying)	
	14 03 00			Flash drying	
15 00 00			Pressing of bales		

Recovery of chemicals

Code			1	2	3
1	2	3	Sub-process	Technique	Operation
16 00 00			Evaporation		
	16 01 00			Vacuum evaporation	
	16 02 00			Back pressure evaporation	
	16 03 00			Thermocompression	
17 00 00			Recovery of chemicals		
	17 01 00			Magnesium recovery	
	17 02 00			Natrium recovery by the STORA-method	
	17 03 00			Natrium recovery by the Billerud-SCA-method	
	17 04 00			Cross-recovery	
18 00 00			Manufacture of sulphite alcohol		

MANUFACTURE OF MECHANICAL OR SEMI-CHEMICAL PULP: 34 11 11

Code			1	2	3
1	2	3	Sub-process	Technique	Operation
19 00 00			Service		
	19 01 00			Raw materials handling	
	19 02 00			Transportation of materials in process	
	19 03 00			Regulation of concentrations, levels and flows	
	19 04 00			Preparation of process water	
	19 05 00			Generation of energy or heat	
	19 06 00			Bark handling	
	19 07 00			Recovery of fibres and backwater	
	19 08 00			Heat recovery	
	19 09 00			Product and process control	
	19 90 00			Other kind of service	

MANUFACTURE OF SULPHATE PULP: 34 11 12

Code			1	2	3
1	2	3	Sub-process	Technique	Operation
01 00 00			Crosscutting		
	01 01 00			Crosscutting in beam crosscutting saws	
	01 02 00			Crosscutting in slashers	
	01 03 00			Crosscutting in band saws	
02 00 00			Barking		
	02 01 00			Barking in wet drum barkers	
	02 02 00			Barking in dry drum barkers	
	02 03 00			Barking in parallel barking machines	
	02 04 00			Barking in knife barking machines	
	02 90 00			Barking in other kind of barking machines	
03 00 00			Chipping		
		03 00 01			Chipping (multi-knife chipping machines)
		03 00 02			Aftertreatment in disintegrator
		03 00 03			Chip screening
		03 00 04			Additional disintegration in re-chipper
		03 00 05			Screening in grit trap
04 00 00			Pretreatment of chips (impregnation)		
	04 01 00			Pretreatment in hot water or steam	
	04 02 00			Pretreatment in chemicals	
05 00 00			Digesting		
	05 01 00			Batch digesting	
	05 02 00			Continuous digesting	
06 00 00			Coarse screening		
		06 00 01			Coarse screening in knot strainers
		06 00 02			Dewatering
		06 00 03			Coarse screening in separators
		06 00 04			Grinding of reject pulp (knots)

MANUFACTURE OF SULPHATE PULP: 34 11 12

Code			1	2	3
1	2	3	Sub-process	Technique	Operation
07 00 00			Pulp washing		
	07 01 00			Pressing	
	07 02 00			Washing on filters	
	07 03 00			Washing in pulp containers	
	07 04 00			Washing in batch digester	
	07 05 00			Washing in continuous digester	
	07 06 00			Washing in continuous diffuser (radial washing)	
	07 07 00			Washing in diffuser	
08 00 00			Fine screening		
		08 00 01			Fine screening on centrifugal screens
		08 00 02			Separation of grit in vortex cyclones
		08 00 03			Fine screening of reject pulp
		08 00 04			Grinding of reject pulp (see 06 00 04)
09 00 00			Bleaching		
	09 01 00			Chlor-alkali bleaching	
		09 01 01			Manufacture of bleaching liquid
		09 01 02			Bleaching
	09 02 00			Oxygen bleaching	
10 00 00			Pulp thickening		
	10 01 00			Thickening in sieb-cylinder	
	10 02 00			Thickening in vacuum-thickener	
11 00 00			Pulp lifting		
	11 01 00			Pulp lifting in Fourdrinier section	
	11 02 00			Pulp lifting in cylinder vat machine	
12 00 00			Pressing		

MANUFACTURE OF SULPHATE PULP: 34 11 12

Code			1	2	3
1	2	3	Sub-process	Technique	Operation
13 00 00			Drying		
	13 01 00			Cylinder drying	
	13 02 00			Hot air drying (fan drying)	
	13 03 00			Flash drying	
14 00 00			Pressing of bales		
Recovery of chemicals					
15 00 00			Black liquor oxidation		
	15 01 00			Oxidation with the BT-system	
	15 02 00			Oxidation with the BCRC-system	
	15 03 00			Oxidation with the champion-system	
16 00 00			Evaporation		
	16 01 00			Vacuum evaporation	
	16 02 00			Back-pressure evaporation	
	16 03 00			Thermocompression	
17 00 00			Treatment of gases and condensates		
18 00 00			Recovery of chemicals		
	18 01 00			Burning of black liquor in soda recovery boiler	
	18 02 00			Burning of black liquor in Tomlinson unit	
	18 90 00			Other method of recovery (Babrock & Wilcox)	
19 00 00			Causticising		
	19 01 00			Causticising by the Dorr-system	
	19 02 00			Causticising by the Celleco-system	
	19 03 00			Causticising by the EIMCO-system	

MANUFACTURE OF SULPHATE PULP: 34 11 12

Code			1	2	3
1	2	3	Sub-process	Technique	Operation
20 00 00			Lime sludge reburning		
21 00 00			Manufacture of soap and resin		
22 00 00			Service		
	22 01 00			Raw materials handling	
	22 02 00			Transportation of materials in process	
	22 03 00			Regulation of concentrations, levels and flows	
	22 04 00			Preparation of process water	
	22 05 00			Generation of energy and heat	
	22 06 00			Bark handling	
	22 07 00			Recovery of fibres and backwater	
	22 08 00			Heat recovery	
	22 09 00			Product and process control	
	22 90 00			Other kind of service	

MANUFACTURE OF SULPHITE PULP: 34 11 13

Code			1	2	3
1	2	3	Sub-process	Technique	Operation
01 00 00			Crosscutting		
	01 01 00			Crosscutting in beam crosscutting saws	
	01 02 00			Crosscutting in slashers	
	01 03 00			Crosscutting in band saws	
02 00 00			Barking		
	02 01 00			Barking in wet drum barkers	
	02 02 00			Barking in dry drum barkers	
	02 03 00			Barking in parallel barking machines	
	02 04 00			Barking in knife barking machines	
	02 90 00			Barking in other kind of barking machines	
03 00 00			Chipping		
		03 00 01			Chipping (multi-knife chipping machines)
		03 00 02			Aftertreatment in disintegrator
		03 00 03			Chip screening
		03 00 04			Additional disintegration in re-chipper
		03 00 05			Screening in grit traps
04 00 00			Pretreatment of chips (impregnation)		
	04 01 00			Pretreatment in hot water or steam	
	04 02 00			Pretreatment in chemicals	
05 00 00			Digesting (acid sulphite: pH 1.5-2; bi-sulphite: pH 4-6; neutral sulphite: pH 6-9)		
			Calcium base		
	05 01 00			Batch	
	05 02 00			Continuous	
			Magnesium base		
	05 03 00			Batch	
	05 04 00			Continuous	

MANUFACTURE OF SULPHITE PULP: 34 11 13

Code			1	2	3
1	2	3	Sub-process	Technique	Operation
			Natrium base		
	05 05 00			Batch	
	05 06 00			Continuous	
			Ammonium base		
	05 07 00			Batch	
	05 08 00			Continuous	
			Combined base		
	05 09 00			Two stage	
06 00 00			Coarse screening		
		06 00 01			Coarse screening in knot strainers
		06 00 02			Dewatering
		06 00 03			Coarse screening in separators
		06 00 04			Grinding of reject pulp (knots)
07 00 00			Pulp washing		
	07 01 00			Pressing	
	07 02 00			Washing on filters	
	07 03 00			Washing in pulp container	
	07 04 00			Washing in batch digester	
	07 05 00			Washing in continuous digester	
	07 06 00			Washing in continuous diffuser (radial washing)	
	07 07 00			Washing in diffuser	
08 00 00			Fine screening		
		08 00 01		Fine screening	
		08 00 02		Removal of resin	
		08 00 03		Fine screening of reject pulp	
		08 00 04		Grinding of reject pulp (see 06 00 04)	

MANUFACTURE OF SULPHITE PULP: 34 11 13

Code			1	2	3
1	2	3	Sub-process	Technique	Operation
09 00 00			Bleaching		
	09 01 00			Chloralkali bleaching	
		09 01 01			Manufacture of bleaching liquid
		09 01 02			Bleaching
	09 02 00			Oxygen bleaching	
10 00 00			Pulp thickening		
	10 01 00			Thickening in sieb-cylinder	
	10 02 00			Thickening in vacuum-thickener	
11 00 00			Pulp lifting		
	11 01 00			Pulp lifting in Fourdrinier section	
	11 02 00			Pulp lifting in cylinder vat machine	
12 00 00			Pressing		
13 00 00			Drying		
	13 01 00			Cylinder drying	
	13 02 00			Hot air drying (fan drying)	
	13 03 00			Flash drying	
14 00 00			Pressing of bales		
Manufacture of digesting liquid and recovery of chemicals					
15 00 00			Manufacture of digesting liquid		
	15 01 00			Production of SO_2 through Kies-roasting	
	15 02 00			Production of SO_2 through sulphur burning	
16 00 00			Evaporation		
	16 01 00			Vacuum evaporation	
	16 02 00			Back pressure evaporation	
	16 03 00			Thermocompression	

MANUFACTURE OF SULPHITE PULP: 34 11 13

Code			1	2	3
1	2	3	Sub-process	Technique	Operation
17 00 00			Recovery of chemicals		
	17 01 00			Magnesium recovery	
	17 02 00			Natrium recovery with STORA-method	
	17 03 00			Natrium recovery with Billerud-SCA-method	
	17 04 00			Ammonium burning	
	17 05 00			Cross-recovery	
	17 90 00			Other method of recovery	
18 00 00			Manufacture of sulphite alcohol		
19 00 00			Service		
	19 01 00			Raw materials handling	
	19 02 00			Transportation of materials in process	
	19 03 00			Regulation of concentrations, levels and flows	
	19 04 00			Preparation of process water	
	19 05 00			Generation of energy and heat	
	19 06 00			Bark handling	
	19 07 00			Recovery of fibres and backwater	
	19 08 00			Heat recovery	
	19 09 00			Product and process control	
	19 90 00			Other kind of service	

MANUFACTURE OF PAPER AND PAPERBOARD: 34 11 20

Code			1	2	3
1	2	3	Sub-process	Technique	Operation
01 00 00			Pretreatment of pulp		
	01 01 00			Water extraction (pumped pulp)	
	01 02 00			Shredding in kneaders or rolling mills (paper refuse, pulp reject)	
	01 03 00			Dissolving in hydrapulper (pulp bales)	
02 00 00			Beating		
	02 01 00			Beating in hollander rolls	
	02 02 00			Beating in conical rolls (Jordan- or Mordenrolls)	
	02 03 00			Beating in disk crushers	
03 00 00			Chemical treatment		
	03 00 01				Sizing
	03 00 02				Coloring
	03 00 03				Filling (e.g. with kaolin)
04 00 00			Purification of the beaten pulp		
	04 01 00			Purification in sand catchers	
	04 02 00			Purification in hydraulic cyclone	
	04 03 00			Purification in knot strainer	
05 00 00			Dewatering		
	05 01 00			Dewatering in Fourdrinier paper machine	
	05 02 00			Dewatering in double Fourdrinier paper machine	
	05 03 00			Dewatering in cylinder vat machine	
06 00 00			Pressing		
	06 01 00			Pressing in straight press with solid press rolls	
	06 02 00			Pressing in reverse press with solid press rolls	
	06 03 00			Pressing in straight press with suction press rolls	
	06 04 00			Pressing in reverse press with suction press rolls	
	06 05 00			Pressing in dual press with suction press rolls	
	06 06 00			Pressing with fluted press	
	06 90 00			Pressing with other kinds or presses	

MANUFACTURE OF PAPER AND PAPERBOARD: 34 11 20

Code			1	2	3
1	2	3	Sub-process	Technique	Operation
07 00 00			Drying		
	07 01 00			Drying in multi-cylinder machine	
	07 02 00			Drying in Yankee-or MG-machine	
	07 03 00			Drying in fan dryer	
08 00 00			Coating		
09 00 00			Glazing		
10 00 00			Calendering		
11 00 00			Winding		
	11 01 00			Winding with tambour-cylinder	
	11 02 00			Winding with electrical winder	
	11 90 00			Winding with other kind of winder	
12 00 00			Final preparation		
	12 01 00			Rewinding	
	12 02 00			Cutting and sheet-laying	
13 00 00			Sorting		
14 00 00			Packing		
15 00 00			Service		
	15 01 00			Raw materials handling	
	15 02 00			Transportation of materials in process	
	15 03 00			Regulation of concentrations, levels and flows	
	15 04 00			Preparation of process water	
	15 05 00			Generation of energy and heat	
	15 06 00			Recovery of fibres and backwater	
	15 07 00			Heat recovery	
	15 08 00			Product and process control	
	15 90 00			Other kind of service	

MANUFACTURE OF FIBREBOARD: 34 11 30

Code			1	2	3
1	2	3	Sub-process	Technique	Operation
01 00 00			Crosscutting		
	01 01 00			Crosscutting in beam crosscutting saws	
	01 02 00			Crosscutting in slashers	
	01 03 00			Crosscutting in band saws	
02 00 00			Barking		
	02 01 00			Barking in wet drum barkers	
	02 02 00			Barking in dry drum barkers	
	02 03 00			Barking in parallel barking machines	
	02 04 00			Barking in knife barking machines	
	02 90 00			Barking in other kind of barking machine	
03 00 00			Chipping		
		03 00 01			Chipping in multi-knife chipping machine
		03 00 02			Aftertreatment in disintegrator
		03 00 03			Chip screening
		03 00 04			Additional disintegration in rechipper
		03 00 05			Screening in grit traps
04 00 00			Defibering		
	04 01 00			Defibering by grinding	
	04 02 00			Defibering by the Masonite-method	
	04 03 00			Defibering by the Asplund-method	
	04 04 00			Defibering of sawdust or cutterdust	
05 00 00			Coarse screening		
	05 01 00			Screening on rotating screen	
	05 02 00			Screening on vibrating screen	
06 00 00			Fine screening		
		06 00 01			Fine screening in centrifugal screens
		06 00 02			Fine screening in vortex cyclones

MANUFACTURE OF FIBREBOARD: 34 11 30

Code			1	2	3
1	2	3	Sub-process	Technique	Operation
		06 00 03			Fine screening of reject pulp
		06 00 04			Grinding of reject pulp
07 00 00			Primary dewatering		
	07 01 00			Dewatering in screw water extractor	
	07 02 00			Dewatering in water extractor with roll	
08 00 00			Adding of chemicals		
09 00 00			Formation of board		
	09 01 00			Formation of board in Fourdrinier section	
				Formation of board in cylinder vat machine	
10 00 00			Drying (insulation fibreboard)		
11 00 00			Press drying		
	11 01 00			Wet pressing	
	11 02 00			Dry pressing	
12 00 00			Hardening		
	12 01 00			Heat treatment	
	12 02 00			Oil treatment	
13 00 00			Conditioning		
14 00 00			Finishing		
		14 00 01			Sawing
		14 00 02			Polishing (or planing)
		14 00 03			Perforating
		14 00 04			Laminating
		14 00 05			Other kind of preparation
15 00 00			Packing		

MANUFACTURE OF FIBREBOARD: 34 11 30

Code			1	2	3
1	2	3	Sub-process	Technique	Operation
16 00 00			Service		
	16 01 00			Raw materials handling	
	16 02 00			Transportation of materials in process	
	16 03 00			Regulation of concentrations, levels and flows	
	16 04 00			Preparation of process water	
	16 05 00			Generation of energy and heat	
	16 06 00			Bark handling	
	16 07 00			Recovery of fibres and backwater	
	16 08 00			Heat recovery	
	16 09 00			Product and process control	
	16 90 00			Other kind of service	

CHAPTER 4

ENVIRONMENTAL POLICY IN SWEDEN

4.1 THE ENVIRONMENTAL PROTECTION ACT

The Environmental Protection Act (SFS 1969:387 with changes SFS 1972:782, SFS 1973:927) and the implementing ordinance associated with this Act - the Environment Protection Ordinance (SFS 1969:388 with changes SFS 1972:224) - came into force on July 1, 1969. The Act (here also referred to as the EPA) states in very general terms the conditions under which real estate (i.e. land, buildings, and installations) can be used for such continuous activities that might cause "disturbances, interferences, or nuisance" to the surrounding environment. The disturbances referred to in the Act are e.g. discharge of waste water, solid matter, or gas, and any other use that may lead to a deterioration of environmental quality. Under the Act, interferences are such things as air pollution, noise, vibrations, light or other such phenomena. Under the provisions of the Act, a number of activities are regulated so that they cannot be undertaken unless permission has been granted by the Franchise Board (FB) or notification has been submitted to the Environment Protection Board (EPB) or to the administration of the county concerned.

The basic principle of the Act is that any disturbances of the type referred to in the Act should be prevented to the greatest possible extent. The Act is also applicable to cases where there is a risk of a deterioration of environmental quality. Furthermore, it is stated in the Act that the location of activities that might cause a deterioration of environmental quality must be chosen so that the purpose of the activity can be achieved with the least possible detriment to environmental quality without the costs being unreasonably high. In order to facilitate the determination of the protective measures that must be undertaken, the Act contains some general rules regarding the considerations that should precede any decision. The five principal aspects that should be considered are: (1) the technical feasibility of emission control measures within various industries, (2) the kind of area in which the activity is to be carried out, (3) the extent of the damage likely to result from the activities, (4) the social benefits of the activities in question, and (5) the costs and other economic consequences of emission control measures.

In view of the general formulation of the permissibility rules, the EPA must basically be regarded as a frame of reference for the authorities. The general statements of the EPA are clarified in the Environment Protection Ordinance (EPO) in which the procedural steps to be taken by the concerned authorities are spelled out in detail. The EPO also specifies the activities covered by the general clauses of the EPA and identifies 38 types of plants which may not be put into operation without permits from the responsible authority. The Ordinance also lists 33 other kinds of plants which may not be erected either, unless an application (or notification) has been submitted to the County Administration. Among the activities obliged to apply for a permit are mining, iron and steel production, pulp and paper production, food processing, manufacture of chemical products and fossil fuel power generation.1)

Permit applications are examined by the Franchise Board for Environment Protection. The Franchise Board is very similar to a court of law and the legal status of its decisions is comparable to a court decision. The procedural rules of the FB states that the Board must consult the governmental and municipal authorities concerned and, in addition, conduct a site inspection. In order to enable other parties to express their views on the matter, the applications must be published in the local newspapers or in some other manner be brought to public attention.

The permit - which is generally valid for a period of 10 years - must contain a specification of the activity covered in the permit and, of course, all the conditions on which the permit is granted. The decision can be appealed to the Government. The right of appeal lies with the applicant, with individual parties affected by the decision and with the EPB. A permit decision that has acquired legal validity is binding on all parties. Provided that the permit holder complies

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1) It should be noted that a permit to engage in activities damaging (or potentially damaging) to environmental quality can always be applied for, even when there is no obligation.

with the conditions stated in the permit, there is no risk that the activity will be prohibited or subjected to other terms than those laid down in the permit decision.

A firm engaged in activities regulated by the EPA can also apply directly to the EPB for an exemption from the obligation to apply to the Franchise Board for a permit. In this context it should be pointed out, however, that an exemption in no way relieves the firm from the obligation to comply with the EPA. In the exemption procedure the applicant must negotiate with the EPB in order to establish the conditions under which the applicant may start or continue the activity. The fundamental difference between a permit decision by the FB and an exemption decision by the EPB is that the latter decision is not legally binding. The exemption is valid only until further notice and can be cancelled if the circumstances so dictate. Another important difference is that an exemption does not give the right to appeal. The main advantage of the exemption procedure is the fact that it is considerably less time-consuming than the process of obtaining a permit.

In order to facilitate decisions concerning the control measures that can "reasonably" be demanded by various industries, the EPB in cooperation with the industries concerned has established a system of source emission standards. These standards are based on the concept of "technical and economic feasibility".

The first set of emission standards was presented by the EPB in the beginning of 1970. In August 1973, the EPB presented a new set of standards reflecting the latest knowledge about the "technical and economic feasibility" of available control measures. These standards primarily apply to residuals discharges into the atmosphere and no standards have so far been established for waterborne residuals. In the case of waterborne residuals the permissible level of discharges is determined on a case-by-case basis where differences in assimilative capacity are among the more important of the factors considered.

4.2 NATIONAL PHYSICAL PLANNING

Physical planning is no new phenomenon in Swedish public administration and has long been used in such sectors of public activity as housing, road construction, etc. However, most of this planning has been of the short-run type and the need for national, long-term, cross-sectoral planning was not fully recognized until the mid-sixties.

The framework for national physical planning in Sweden does not have the form of an Act in which general clauses are listed. Instead the Parliament in 1972 passed a series of recommendations or objectives for future land-use in Sweden. The decisions taken by Parliament include national guidelines of two different kinds: (1) activity guidelines indicating how certain types of activities should be handled in the physical planning at the regional and local levels, and (2) geographical guidelines for the management of certain natural resources in various parts of the country. The geographical guidelines cover above all the coastal areas, but also the mountain areas and certain river valleys.

The legislation decided upon by Parliament simultaneously with the approval of the guidelines was aimed at improving the possibilities for implementation of the general ideas expressed in these guidelines. The new legislation covers three important aspects of national physical planning, namely, (1) the establishment of master plans, (2) specification of compensation and acquisition rules, and (3) determination of conditions for location of certain industrial activities.

The legal right of the Government to order the development of master plans was established in order to ensure that the guidelines for the national physical planning are followed in the process of regional and municipal planning. The Government may prescribe the partial or complete prior approval of the plan if this is deemed necessary in the national interest.

As far as the rules for compensation and acquisition are concerned the provisions of the previous legislation (i.e. the Building Act and the Nature Conservancy Act) entitled the landowner to compensation if land use was restricted in such a way so as to substantially lower the previous value of the land. This rule primarily applied to restrictions on building development. Particularly serious actual or potential damage entitled the landowner to demand that the local authority acquired the land concerned. This right to compensation or "buying out" could also apply to values which were solely referable to anticipated changes in the value of land.

In connection with national physical planning by means of master plans or directives issued under the Nature Conservancy Act, the Government has stated its intention to strengthen the public interest in relation to landowners. Thus, the policy adopted by the Parliament with regard to overall planning implies that compensation is only to be paid in cases of "grave obstructions" of the present land use.

With respect to location of new industry, the inclusion of a new rule in the Building Act provides for central Government to make a comprehensive assessment of the issue, relating considerations of environmental quality management and planning to considerations of labor market policy, regional policy, industrial policy, etc. Before any decision is made, however, consultations must be held with authorities (like, for example, the FB and the EPB), the local administration, trade unions, industry associations, etc.2)

The Government's decision in a location issue is binding for planning under the Building Act. The location decision is also binding for subsequent considerations of the issue under the Environment Protection Act. The Franchise Board may not sanction an activity in cases where an application for a location permit has been rejected by the Government. Conversely, the activity in question must be sanctioned by the Board if a location permit has been granted by the Government. However, it still remains the duty of the FB to specify the detailed conditions to which the activity will have to comply under the Environment Protection Act. Thus, the firm applying for a location permit still has to apply for a permit for its activities under the EPA - after the location issue has been determined by the Government. In fact, the permission granted by the Government can be made conditional on the issue being pursued further within a certain period by an application to the Franchise Board.

Under the Ordinance concerning location assessment for industrial activities, the new assessment procedure is to apply to the establishment of (a) iron and steelworks, metal works, and ferro-alloy works; (b) ground wood mills and pulp and paper mills; (c) plants for the production of petrochemical products; (d) petroleum refineries; (e) nuclear power stations; (f) plants for reprocessing of nuclear fuels; (g) fossil fuel power plants with a power output exceeding 500 MW; (h) plants for manufacturing of fertilizers; and (j) cement factories.

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2) Location permission may only be granted if it is approved by the municipality. Thus, the municipality always has a right of veto in these matters.

4.3 THE ACT ON PRODUCTS HAZARDOUS TO MAN AND TO THE ENVIRONMENT

The Act on hazardous products which was passed by Parliament in 1973 refers to products which due to their chemical or physico-chemical properties and handling are known or suspected to be harmful to man or to the environment. In the Proclamation accompanying this Act, four groups of hazardous products are distinguished: (a) poisons and dangerous substances, (b) pesticides, (c) PCB and PCB products, and (d) other hazardous products. As far as the first group of products is concerned, the Proclamation states that permits or notifications are necessary for manufacturers as well as importers to use or to sell such products. As for pesticides, the Proclamation prescribes registration of the product prior to marketing and use. The Proclamation also states that PCB and related products may not be imported or handled without a permit. The fourth group of products includes all products that contain or have been prepared with hazardous substances and the Proclamation states that the sale of any such product is prohibited.

The general philosophy underlying the rules for manufacturing, handling, importing and marketing products covered by the Act is that the producer/importer "shall take such steps and otherwise observe such precautions as may be necessary to prevent or minimize damage to human beings or the environment". This means that the producer/importer must acquire full knowledge of the composition of the product, assess the hazards associated with its use as far as scientific knowledge at any given time permits, and be prepared to submit all this information to the authorities.

The main responsibility for implementation of this Act rests with the Products Control Board which consists of representatives of various governmental agencies, labor organizations, and industry. This Board is administratively associated with the EPB which has the supervisory power at the national level. On the regional and local levels, this power rests with the County Administration and the Public Health Committees, respectively.

4.4 GOVERNMENT SUBSIDIZATION OF EMISSION CONTROL INVESTMENTS

When the Environment Protection Act came into force on July 1, 1969, it applied not only to new plants and installations but also to plants in operation before that date. Under the provisions of the Act, existing plants were also obliged to install emission control equipment and take other precautions in order to reduce the risk of a deterioration of environmental quality. However, in the explanatory comments accompanying the Act, it was emphasized that since it is, in general, both technically more difficult and economically more costly to reduce emissions from old plants, it would be justified to allow these plants some time for adjustment. In order to induce firms to undertake the necessary control measures as soon as possible, the Government decided to subsidize investments for environmental quality control by existing industrial and municipal plants.(3)

In the 1969 Proclamation on Government Subsidies to Industry for Water and Air Quality Protection Measures, it was stated that existing plants could apply for a subsidy of an amount not exceeding 25 % of the investment cost of the control measure. The subsidization program was planned to be in operation for a period of five years. The amount of money annually available for this purpose was limited to 50 million S.Cr. The allocation of the subsidies was to be the responsibility of the EPB.

In order to be eligible for a subsidy, the investment had to be of importance to the general public. Furthermore, it was stated that plants which were given subsidies were expected to remain in existence for a period long enough to make the cost of control measures justifiable from an economic point of view. Subsidies could also be given to cover part of the costs of connecting an existing plant with the local sewage treatment plant. It was also stated in the Proclamation that subsidies could only be given to firms applying for permits or "exemptions".

In the fall of 1971, when the Swedish economy began to show signs of stagnation, Parliament decided to use the subsidies for emission

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3) The rules for subsidies to municipal sewage treatment plants came into force on July 1, 1968. The size of the subsidy was made dependent upon the degree of treatment at each individual plant, and the higher the degree of treatment, the higher the percentage of the investment cost covered by the subsidy. The subsidy could therefore vary between 30 and 50 %. During the 1971-72 recession this interval was raised to 55-75 % for two limited periods of time, i.e. November 1, 1971 - June 30, 1972 and September 1, 1972 - April 30, 1973. During the five fiscal years from 1968/69 to 1972/73, subsidies of a total amount of 824 million S.Cr. was paid. Approximately 464 million S.Cr. were allocated in accordance with the temporarily raised percentage rates.

control investments to stimulate the economic activity in general and the employment rate in particular. Thus, during the period from November 1, 1971, to June 30, 1972, firms could apply for subsidies covering up to 75 % of the investment costs of emission control measures. A constraint associated with these increased subsidies was that the work should be completed to at least 60 % before June 30, 1972, and special time limits were set for the procurement of machinery and other equipment. In order for the work not to be held up, the EPB and the County Administrations were authorized to allow the work to be started on certain conditions even if all questions concerning the plant's emission control had not been finally settled. In all other respects the same conditions as for the 25 % subsidy applied. A total amount of 300 million S.Cr. over and above the funds already made available for the 25 % subsidies, was reserved for the purpose. Due to the unusual length of the Swedish recession, the policy of increased subsidies was repeated for the period September 1, 1972 - April 30, 1973. This time additional funds of 100 million S.Cr. were made available and the subsidies covered up to 50 % of the investment costs for work started during that period. Apart from these differences, the regulations were identical with those of the previous period.

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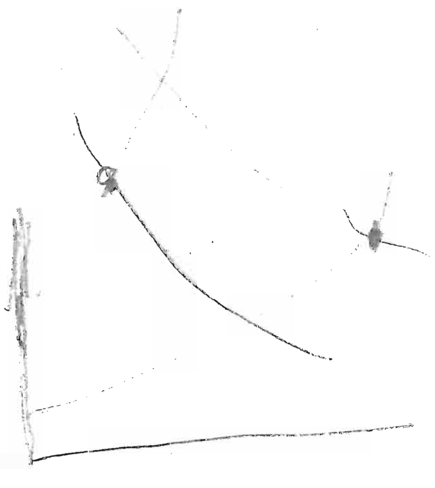

CHAPTER 5

EMISSION CONTROL INVESTMENTS IN SWEDISH INDUSTRY BETWEEN JULY 1, 1969 AND JUNE 30, 1973

A study of the 2,172 applications for government subsidies submitted to the EPB between July 1, 1969 and June 30, 1973 reveals that emission control investments of approximately 1,262 million S.Cr. (in current prices) were completed between July 1, 1969 and June 30, 1973 by plants in operation before July 1, 1969.1) The amount of subsidies to these investments was about 592 million S.Cr. of which roughly 500 million were allocated during the two periods of increased subsidies. In view of the magnitude of this subsidization program, its impact will here be discussed from five different angles. Thus, the following sections will describe the distribution of both the emission control investments and the subsidies among industries, regions, and over time. In the last two sections the effects of these investments on employment and on total discharges will be discussed.

5.1 DISTRIBUTION OF EMISSION CONTROL INVESTMENTS AMONG INDUSTRIES

Between July 1, 1969 and June 30, 1973, the dominating part of the emission control investments by existing plants have taken place in the pulp and paper industry (37 %) and in the iron and steel industry (24 %). This particular distribution of emission control investments can, to a large extent, be explained by the high proportion of total residuals emissions which originate in these industries.

In 1969, for example, the pulp and paper industry was responsible for approximately 90 % of total discharges of BOD_7 and for close to

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1) It should be noted that this figure differs from the investment costs as estimated by the firms. The reason for this difference is that the EPB in their consideration of the subsidy application did not always accept the firm's cost estimate. If, in the opinion of the EPB, some of the investment costs were incurred for other reasons than emission control, the EPB would reduce the "subsidy base" accordingly. Since it was in the interest of the individual firms to exaggerate the costs, the "subsidy base" might represent a slightly more realistic estimate of the "true" investment costs than the firms own estimates.

20 % of total SO_2-discharges. The iron and steel industry, in turn, accounted for roughly 20 % of total discharges of particulates and for about 5 % of total SO_2-emissions. The magnitude of the emissions from these two industries partly explains why the degree of subsidization has been higher here than for the industry as a whole. An additional explanatory factor can be found in the fact that these industries suffered from severe unemployment problems during the 1971-72 recession. The distribution of the emission control investments and the subsidies among industries is shown in Table 5:1.

5.2 DISTRIBUTION OF EMISSION CONTROL INVESTMENTS AMONG REGIONS

As pointed out in chapter 4, the unemployment problems arising during the 1971-72 recession led to the temporary use of so-called "increased subsidies" to emission control investments for two limited time periods. The regional distribution of emission control investments to a certain extent reflects the regional differences in the unemployment rate. The so-called "forest counties" (i.e. counties S, W, X, Y, Z, AC and BD in Figure 5:1 had an average unemployment rate of 3.6 % in 1971 compared with 2.3 % for the rest of the country. In 1972 the corresponding percentages were 3.8 % and 2.4 % respectively.

Even though these counties accounted for only about 20 % of the total work force, approximately 43 % of total emission control investments and 45 % of all subsidies were allocated to these regions. This could to a large extent be explained by the fact that the major part of the plants located in these regions (i.e. pulp mills and iron & steel plants) had both high unemployment and large emissions.

The regional unemployment rates and the regional distribution of emission control investments and subsidies are shown in Table 5:2.

5.3 DISTRIBUTION OF EMISSION CONTROL INVESTMENTS OVER TIME

The general idea underlying the introduction of the increased subsidies for emission control investments by existing plants was to change the timing of these investments and thereby affect the employment rate favorably. From Figures 5:2 and 5:3 it can be seen that the introduction of the 75 % investment cost subsidy (November 1, 1971) led to a very sharp increase in emission control investment, especially during

Table 5:1. Capital expenditures (as accepted by the EPB) and subsidies for emission control measures by plants in operation before July 1, 1969. (Current prices. Thousand S.Cr.)

Industry	Emission control investment July 1,1969 - July 1, 1973	Emission control investment in % of total investment 1970-1973	Share of total emission control investment	Subsidies	Subsidies in percent of costs	Share of total subsidies
Mining industry (incl. stone quarrying)	32,168	2.1	2.5	15,423	47.9	2.6
Food industry	96,579	3.5	7.7	39,061	40.4	6.6
Textile-,clothing, and leather industry	23,120	3.0	1.8	10,804	46.7	1.8
Wood products industry	15,359	0.7	1.2	5,471	35.6	0.9
Pulp and paper industry	472,000	7.6	37.4	225,166	47.7	38.0
Chemical industry	86,151	2.1	6.8	38,431	44.6	6.5
Stone and clay industry	116,437	11.3	9.2	58,218	50.0	9.8
Iron and steel industry*	306,473	8.5	24.3	153,277	50.0	25.9
Manufacturing industry (surface treating of metals)	67,750	0.7	5.4	29,106	43.0	4.9
Other industries	45,981	n.a.	3.6	17,867	38.9	3.0
Total	1 262,018		100.0	592,824	47.0	100.0

* Including the ferro-alloy industry.

Source: EPB Decision Protocols up to July 1, 1973.

Table 5:2. Regional unemployment rates 1971-73. Regional distribution of investment costs for emission control purposes and regional distribution of government subsidies. (Thousand S.Cr. Current prices)

County		Unemployment rate, percent			Investment costs (as acc. by the EPB)	Percent of tot. investment	Subsidies	Percent of tot. subsidies	Subsidy percentage
		1971	1972	1973					
Stockholm	(A,B)	1.9	2.3	1.8	48,303	3.8	20,270	3.4	42.0
Uppsala	(C)	~~22.0~~ 2,0	2.7	2.8	31,756	2.5	17,234	2.9	54.3
Södermanland	(D)	2.8	3.2	2.2	41,713	3.3	22,910	3.9	54.9
Östergötland	(E)	2.8	2.7	2.4	28,100	2.2	12,234	2.1	43.5
Jönköping	(F)	2.3	2.1	1.6	43,072	3.4	17,223	2.9	40.0
Kronoberg	(G)	2.1	2.2	2.1	27,405	2.2	13,007	2.2	47.5
Kalmar	(H)	2.1	2.9	2.3	24,270	1.9	9,649	1.6	39.8
Gotland	(I)	3.6	2.1	2.6	15,577	1.2	6,387	1.1	41.0
Blekinge	(K)	3.0	3.1	2.6	21,638	1.7	10,581	1.8	48.9
Kristianstad	(L)	2.0	2.3	1.7	42,283	3.4	16,917	2.9	40.0
Malmöhus	(M)	2.6	2.8	2.2	80,945	6.4	34,103	5.8	42.1
Halland	(N)	1.6	1.6	1.6	19,567	1.6	8,493	1.4	43.4
Göteborg och Bohus	(O)	2.2	2.3	2.3	41,139	3.3	17,549	3.0	42.7
Älvsborg	(P)	2.5	1.9	1.8	101,682	8.1	46,411	7.8	45.6
Skaraborg	(R)	2.1	1.6	2.0	44,971	3.6	20,980	3.5	46.7
Värmland	(S)	3.8	4.7	4.0	104,251	8.3	57,744	9.7	55.4
Örebro	(T)	2.4	2.5	2.4	79,422	6.3	39,391	6.6	49.6
Västmanland	(U)	2.7	2.8	3.0	27,548	2.2	13,307	2.2	48.3
Kopparberg	(W)	2.6	2.6	2.7	64,693	5.1	31,047	5.2	48.0
Gävleborg	(X)	2.6	3.2	3.5	139,444	11.1	68,476	11.6	49.1
Västernorrland	(Y)	3.5	4.1	4.3	122,574	9.7	58,508	9.9	47.7
Jämtland	(Z)	3.8	3.1	3.3	1,208	0.1	666	0.1	55.1
Västerbotten	(AC)	3.6	4.5	3.7	62,759	5.0	28,217	4.8	45.0
Norrbotten	(BD)	5.5	4.6	5.4	47,698	3.8	21,520	3.6	45.1
Total		2.5	2.7	2.5	1,262,018		592,824		47.0

Figure 5:1. The counties of Sweden

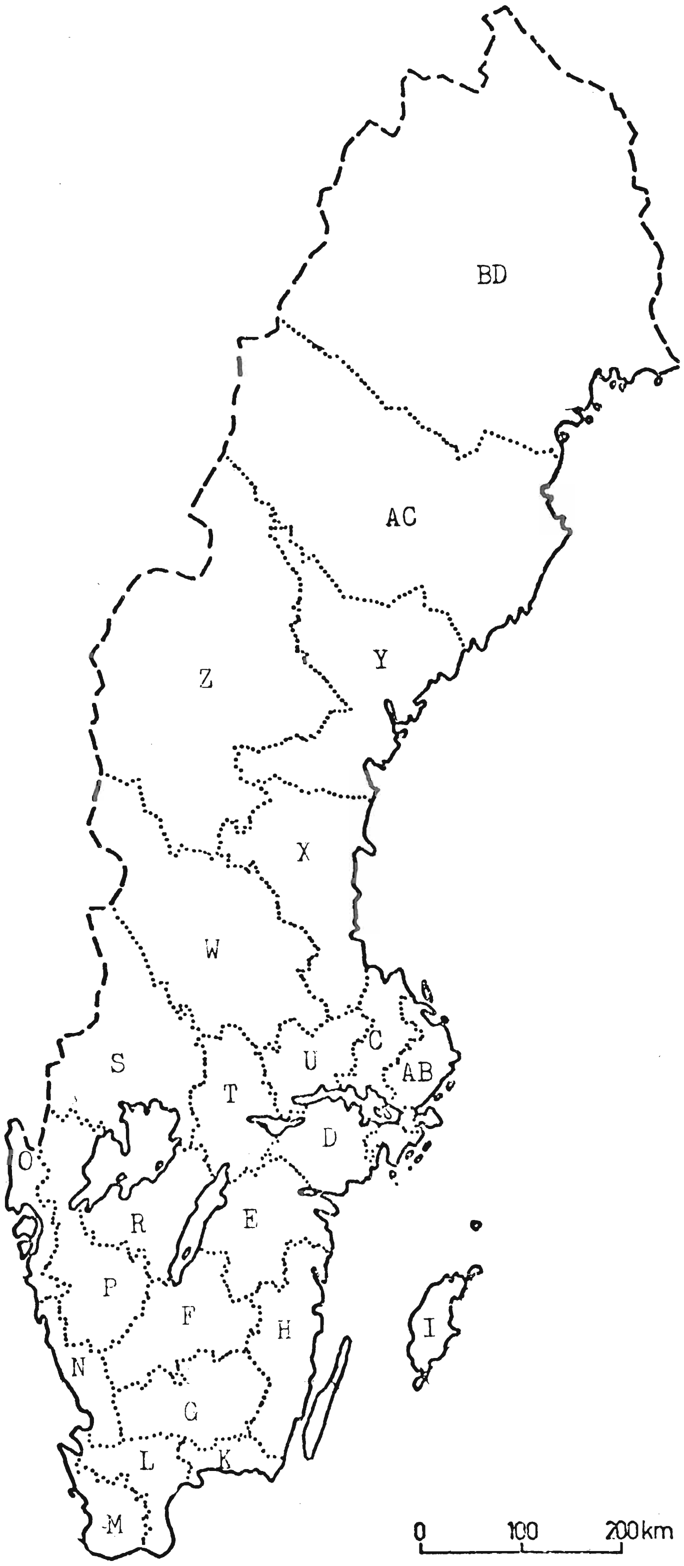


Figure 5:2. Distribution of emission control investment over time 1969-1974
(Thousand S.Cr, current prices)

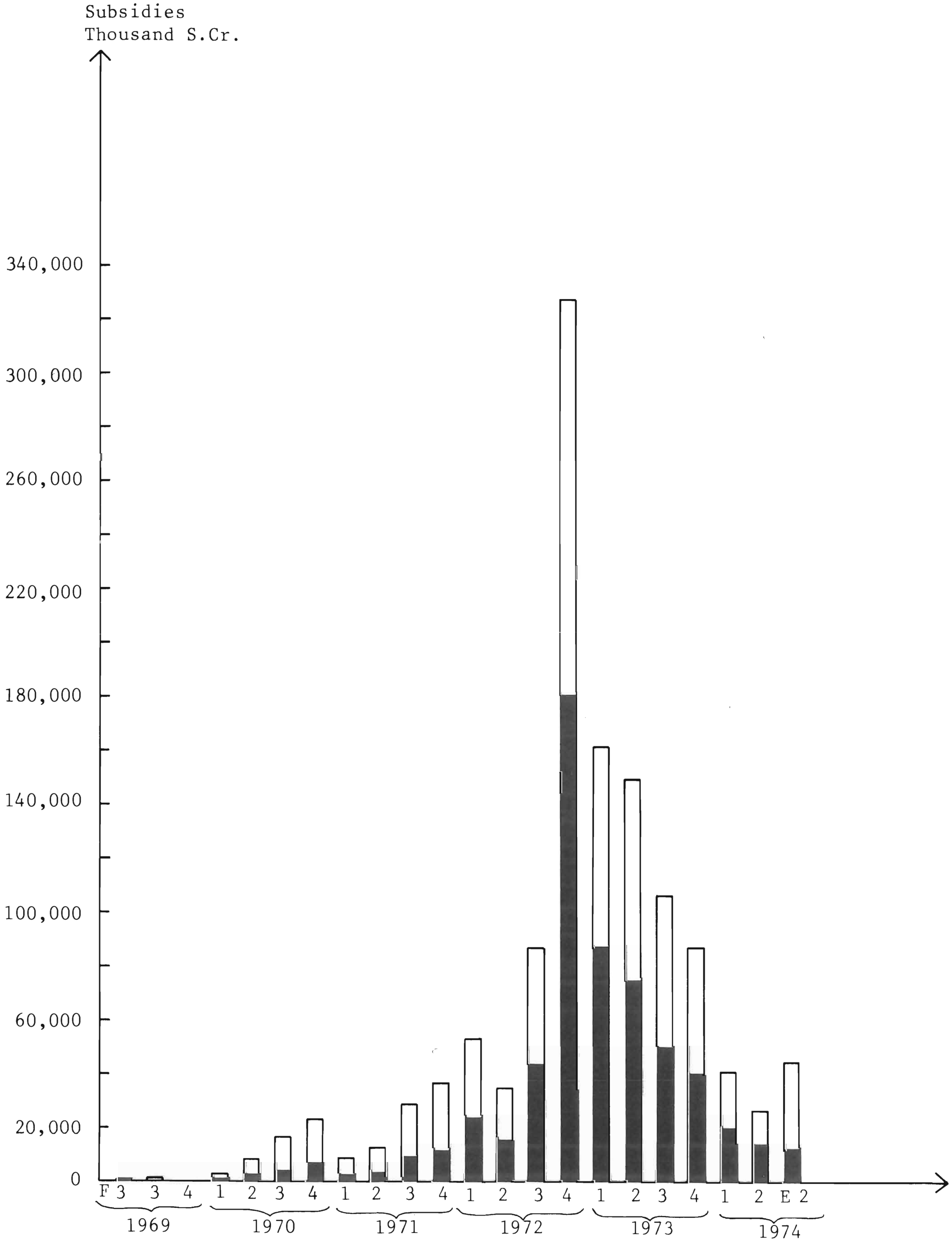
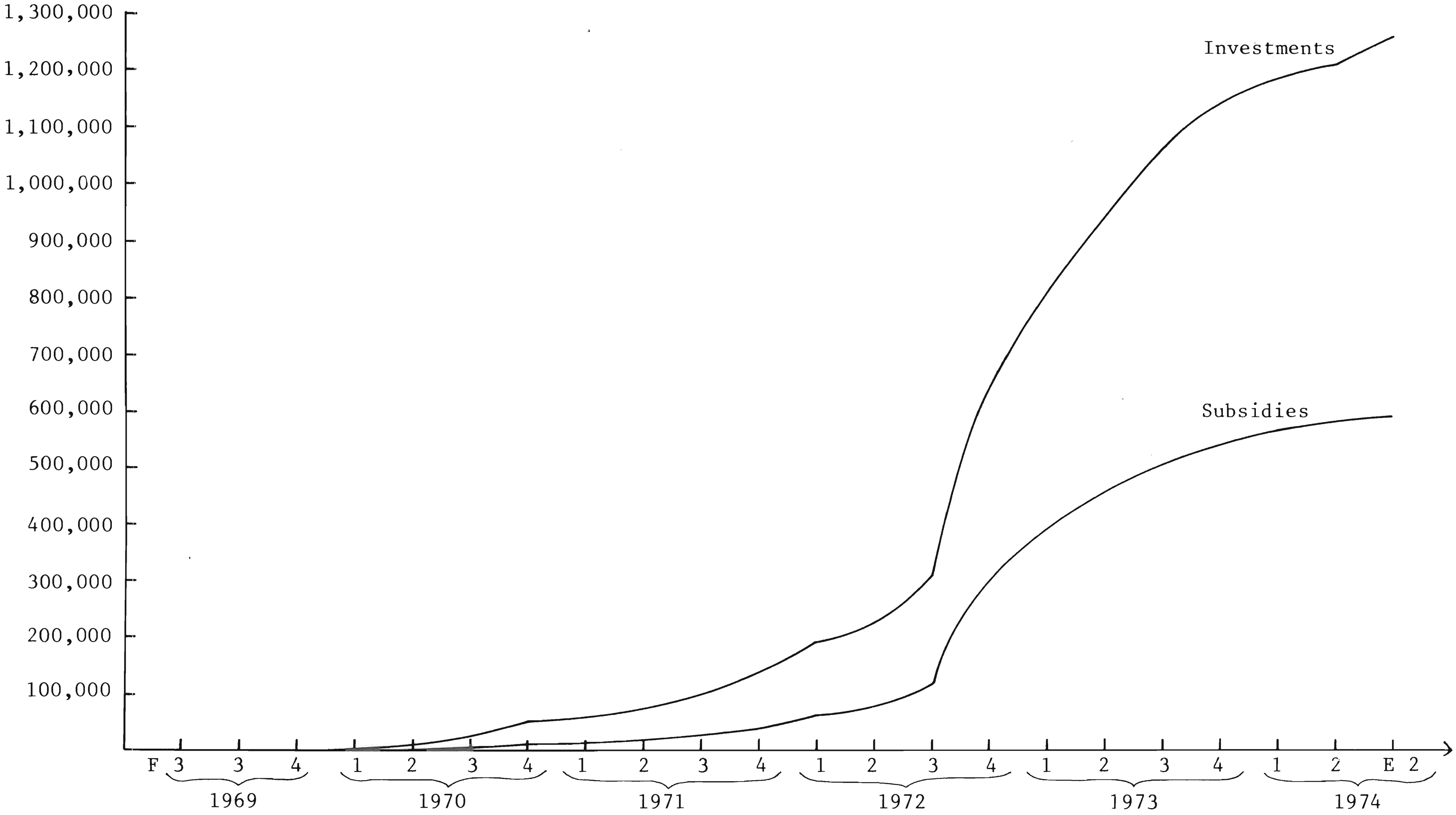


Figure 5:3. Emission control investments and subsidies accumulated over time 1964-1974

(Thousand S.Cr, current prices)



the second half of 1972. However, in Figures 5:2 and 5:3, investments are accounted for at the date of completion. Under the assumption that expenditures are, in general, evenly distributed over the gestation period, Figures 5:2 and 5:3 probably represent a certain overestimate of the lag between the subsidy-decision by the EPB and the economic impact of the investment. Even if it is difficult to specify with any exactness the degree to which the increased subsidies have speeded up the start (and completion) of emission control investment, the data seem to suggest that the "gain in time" might lie somewhere between 1 and 2 years.

5.4 THE EFFECTS ON EMPLOYMENT OF THE EMISSION CONTROL INVESTMENTS UNDERTAKEN DURING THE PERIODS OF INCREASED SUBSIDIES

In the instructions to the EPB concerning the allocation of the increased subsidies it was emphasized that the employment effects of the emission control investments should be given special consideration. As a result, the EPB instructed applicants to include an estimate of the direct employment effects (measured in man-days) of the investments. An analysis of these applications showed that in certain industries (i.e. the pulp & paper, iron & steel, stone & clay, and chemical industries) the <u>direct</u> employment effects of the emission control investments might have been equivalent to a 20-30 % reduction in the unemployment rate. (See Table 5:3.)

Estimates made by the EPB of the <u>indirect</u> employment effects (i.e. the employment generated in other sectors of the economy by the large orders of residuals treatment equipment) indicate that these effects were about twice as large as the direct effects, or 7-8,000 man-years. Even if these figures might represent a certain overestimation of the total employment effects, the data seem to indicate that the increased subsidies did have a significant effect on employment during the later phase of the 1971-72 recession - especially in the pulp and paper industry.

5.5 THE EFFECTS ON DISCHARGES OF THE SUBSIDIZED EMISSION CONTROL INVESTMENTS BETWEEN JULY 1, 1969 AND JUNE 30, 1973

In 1969 the BOD_7-discharges from industry as a whole were estimated to 1,950 tons/day. The pulp and paper industry accounted for approximately

Table 5:3. Distribution of direct employment effects of increased subsidies for emission control investments by plants in operation before July 1, 1969

Industry	Man-days		Man-years		Percent of employment		Unemployment in % (AKU)	
	1972	1973	1972	1973	1972	1973	1972	1973
Mining industry	6,970	3,485	34	16	0.2	0.1	1.8	2.9
Food industry	22,793	15,454	106	72	0.1	0.1	3.0	2.8
Textile-, clothing, and leather ind.	9,964	8,132	48	39	0.1	0.05	6.0	4.2
Wood products industry	2,413	5,882	11	27	0.0	0.03	2.2	2.5
Pulp and paper industry	189,276	118,268	878	537	1.3	0.8	2.1	2.3
Chemical industry	46,287	25,953	215	128	0.5	0.3	1.8	2.2
Stone and clay industry	53,911	33,670	250	157	0.6	0.4	2.7	3.0
Iron and steel industry	140,141	72,392	634	337	0.8	0.4	1.6	2.1
Manufacturing industry	24,656	15,128	114	70	(0.1)	(0.1)	2.7	2.8
Total	496,411	298,364	2,290	1,383				

Sources: EPB Decision Protocols up to July 1, 1973. Arbetskraftsundersökningen (AKU) 1972, 1973, Statistiska centralbyrån.

95 % of this amount or roughly 1,850 tons/day. The emission control investments undertaken by industry between July 1, 1969 and July 1, 1973 have resulted in a reduction of BOD_7-discharges of 447 tons/day or by 23 %. Approximately 87 %, or 390 tons/day, of this reduction was accomplished by the pulp and paper industry. For suspended solids the total reduction of discharges amounted to 386 tons/day, 83 % or 320 tons/day of which were attributable to the pulp and paper industry.

Industrial discharges of particulates to the atmosphere were estimated in 1969 to be roughly 850 tons/day. The emission control investments completed during the four fiscal years 1969/70 to 1972/73 have led to a reduction of particulates emissions of 564 tons/day which is around two thirds of the 1969 rate of emissions. Roughly 50 % of this reduction was accomplished by the stone and clay industry (including stone quarrying) and about 28 % by the iron and steel industry.

In 1969, total industrial SO_2-discharges (including discharges from fossil fuel power stations) were about 1,350 tons/day. The pulp and paper industry accounted for roughly 40 % or 555 tons/day of these emissions. The emission control investments during these four years have resulted in an 8 % reduction of industrial SO_2-discharges. Almost 92 % of this reduction (102 tons/day) was attributable to the pulp and paper industry.

The total effects on discharges of emission control investments completed during the fiscal years 1969/70 to 1972/73 are summarized in Table 5:4.

5.6 CONCLUSIONS

In view of the preceding description of the effects of the emission control investments undertaken with varying degrees of government subsidies, some general remarks on the merits and demerits of the subsidization policy can be made.

The data as presented in the preceding sections seem to give some support to the argument that the use of increased subsidies did, in fact, have a substantial effect on the employnent situation during the later phase of the 1971-72 recession. There also seems to be some support for the hypothesis that emission control investments were speeded up by the increased subsidies. The shift in time is difficult to determine with any precision but could perhaps be estimated to be of the magnitude of 1-2 years.

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2. Manipulative information to EPB.

Table 5:4. Reduction of discharges resulting from emission control investments completed between July 1, 1969 and July 1, 1973 (Tons/day)

	Waterborne residuals									Airborne residuals							
Industry	BOD_7	Susp. solids	Lignine	Metals	Acids	Oils & emulsions	Ammonia	Org. subst.	Other	Particulates	SO_2	Sulphur compounds	HNO_3, NO, NO_2, NH_3	Flourine, flourides	Halogenes	Hydrocarbons	CO
Mining ind. (incl. stone quarrying)		22.5		0.1						77.0							
Food ind.	34.7									2.5							
Textile, clothing & leather ind.	6.6	0.4								0.2							
Wood products industry	8.1	1.5								2.0							
Pulp and paper ind.	833 390.3	320.0	110.7						0.7	51.3	102.4	17.1				2.5	
Chemical industry	6.5	0.6			17.1	1.4	5.5	5.5	0.5	10.1	1.0	3.9	1.3			6,8	
Stone and clay ind.	0.1									230.8	0.7	0.2					103.5
Iron and steel ind.		40.7		10.0	5.1	3.0			0.5	159.1	7.3		0.1	0.6			
Manufact. ind. (surface treating of metals				1.8	0.2	0.1			0.4	0.8				2.4			
Other industries	0.8			0.1	1.5	0.2				30.3							
Total	447.1 1950	385.7	110.7	12.0	23.9	4.70	5.5	5.5	2.1	564.1	114.4	21.2	1.4	3.0		9.3	103.5

Source: Subsidy applications to the EPB, ~~Am~~ Endast de anläggningar som erhållit bidrag till miljövårdsinvesteringar enligt [illegible]. Uppgift lämnat

application. [illegible] (brev, [illegible])

However, the use of increased subsidies also had some negative effects which partly offset the positive effects referred to above. The strict time limits accompanying the increased subsidies led to a sharp increase in the demand for residuals treatment equipment. Due to the limited production capacity of the producers of such equipment, this increase in demand led to certain price increases. The short planning period allowed for investments eligible for increased subsidies resulted in some misjudged investments necessitating expensive remodelling later on. The time constraints also favored the installation of conventional treatment techniques at the expense of the development of process-integrated solutions, and the investments could therefore not always be made a part of the companies' long-term environmental control plans. Thus, to a certain extent the increased subsidies might have served to maintain old production equipment in operation. It is also possible that some firms in order to take advantage of the increased subsidies postponed other investments so that the net effect on total investments was nil.

However, in some cases, the increased subsidies made it possible for the EPB to demand quite far-reaching measures by the firms and to stimulate full scale tests of new technical solutions. In fact, the positive results achieved in this respect so far have motivated the EPB to suggest a reorientation of the subsidization policy in this direction. Thus, for the fiscal year 1974/75 subsidies will be given primarily to firms that want to try new technical solutions to the emission control problems.

CHAPTER 6

EMISSION CONTROL IN THE SWEDISH IRON AND STEEL INDUSTRY BETWEEN JULY 1, 1969 AND JUNE 30, 1973

6.1 BASIC FACTS ABOUT THE SWEDISH IRON AND STEEL INDUSTRY

6.1.1 Size and composition of output

The Swedish production of steel ingots was in 1968 approximately 5.1 million tons. Roughly 26 percent of this production consisted of so-called special steel. According to the answers to a questionnaire circulated in October 1967, steel ingot production was planned to increase to approximately 7 million tons in 1975. It was also estimated that during this period the proportion of special steel would increase to approximately 30 percent. Furthermore, there was a clear indication in the plans that the proportions in which the three principal methods of steel-making (i.e. basic oxygen furnaces, open hearth furnaces, and electric arc furnaces) were used would change substantially. Actual steel ingot production and its distribution between processes for the years 1968-1973 is shown in Table 6:1 and Figure 6:1.

Swedish raw steel production capacity in 1973 was approximately 6.86 million tons. Thus the actual 1973 production implied a rate of capacity utilization of roughly 83 percent. The distribution of the production capacity between the various types of furnaces is shown in Table 6:2.

A characteristic feature of the Swedish iron and steel industry is the high proportion of the steel production which is manufactured in electric arc furnaces. Whereas the proportion of steel production made in furnaces of this type is around 42 % in Sweden, it is only around 15-17 % in the U.S., the U.K. and Japan and 12 % in the European Community. The size and the structure of the Swedish iron and steel industry compared to the major steel producers in the world has, as will be discussed below, some important implications for the generation of residuals within the industry.

Table 6:1. Swedish steel ingot production by processes 1968-1973

	1968		1969		1970		1971		1972		1973	
	T.tons	%	T.tons	%	T.tons	%	T.tons	%	T.tons	%	T.tons	%
Basic Oxygen Furnaces	1,726.2	33.9	1,781.7	33.5	1,941.1	35.3	1,947.6	37.0	1,935.6	36.8	2,143.6	37.9
Open Hearth Furnaces	1,380.7	27.1	1,351.6	25.4	1,274.5	23.2	1,182.1	22.4	1,100.1	20.9	1,151.6	20.3
Electric Arc Furnaces	1,988.4	39.0	2,188.9	41.1	2,281.4	41.5	2,141.7	40.6	2,221.3	42.3	2,368.1	41.8
	5,095.3	100.0	5,322.2	100.0	5,497.0	100.0	5,271.4	100.0	5,257.0	100.0	5,663.3	100.0

Source: Svensk Järnstatistik 1973 (Jernkontoret, 1974), tabell 5a.

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5663
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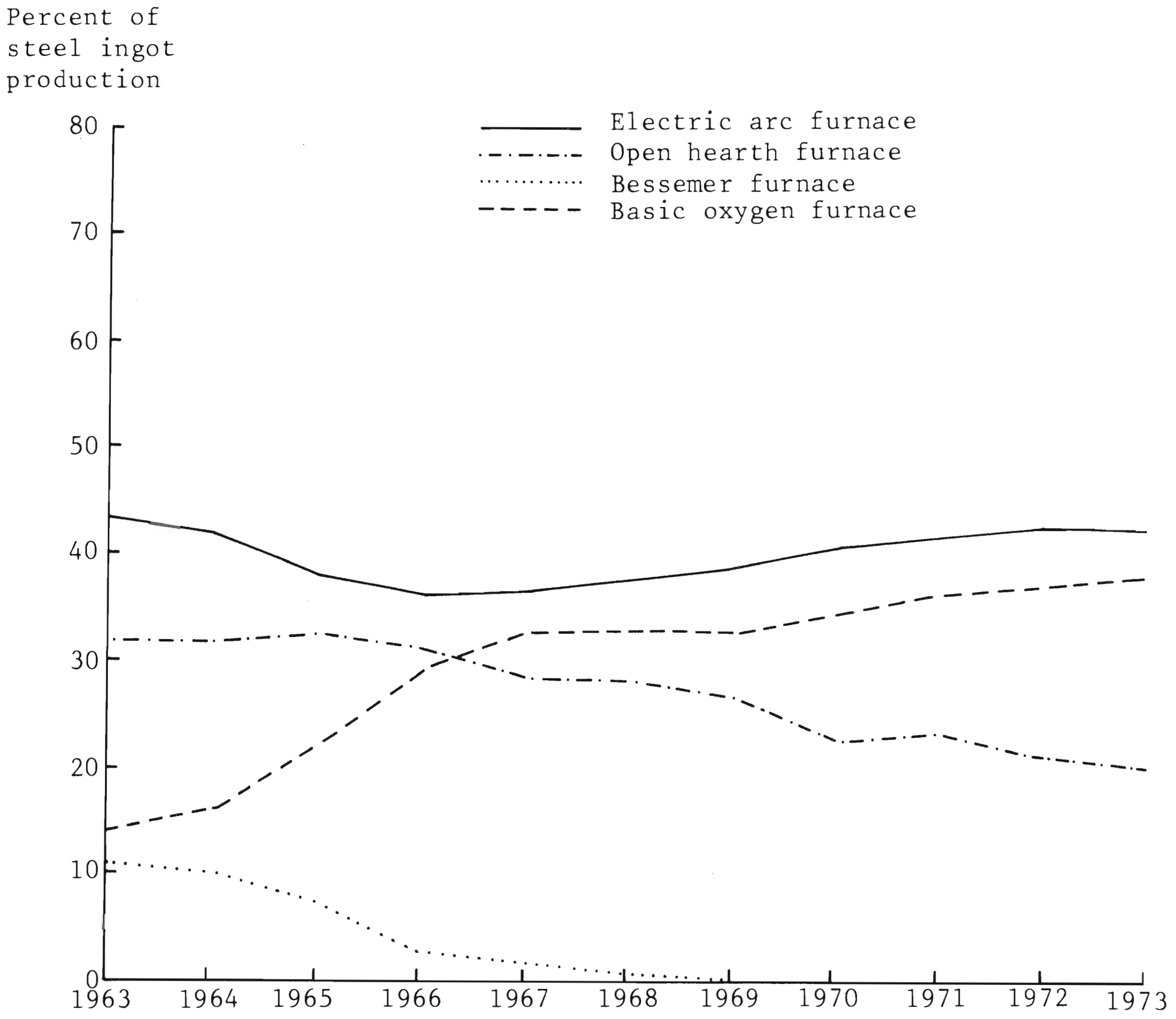
Figure 6:1. Percentage of steel ingot production by different processes 1963-1973



Source: Bergshantering 1972, SOS, Statistiska centralbyrån. Stockholm 1973, p. 40.

Table 6:2. Distribution of production capacity and number of furnaces 1971-1973

	1971		1972		1973	
	Number	T.tons/ year	Number	T.tons/ year	Number	T.tons/ year
Thomas converters	3	160	-	-	-	-
Open hearth furnaces (acid)	16	499	15	525	15	592
Open hearth furnaces (basic)	13	878	12	795	13	857
Electric arc furnaces*	63	2,354	62	2,456	60	2,551
Induction furnaces*	36	225	35	230	41	233
Basic oxygen furnaces (LD and Kaldo)	8	2,140	9	2,500	9	2,735
Other converters (AOD and CLU)	-	-	-	-	2	165
		6,001		6,097		6,858

* Including furnaces in the ferro-alloy industry.
Source: Svensk Järnstatistik 1973 (Jernkontoret, 1974), tabell 15.

The smallness (by international standards) of the Swedish iron and steel industry can be seen from Table 6:3 which shows the distribution of world steel production 1964-1973.

6.1.2 Size and geographical distribution of plants

From a national viewpoint, the Swedish iron and steel industry consists of relatively large plants. In 1968, almost 90 % of the total number of employees in the iron and steel industry were working at plants with more than 500 employees. For the Swedish industry as a whole this proportion was only around 30 %.

Another characteristic of the Swedish iron and steel industry is that production is quite unevenly distributed. In 1968, the three largest plants accounted for 64 % of total production. For the five largest plants this share was 73 %. The size-distribution of the Swedish steel plants in 1968 and 1973 is shown in Table 6:4.

Table 6:3. Distribution of world steel production 1964-1973. (Percent)

	U.S.	CECA_6	CECA_9	Japan	Canada	Sweden	World prod. Million tons
1964	26.5	19.1	25.2	9.2	1.9	1.0	434
1965	26.1	18.9	25.0	9.0	2.0	1.0	456
1966	25.8	18.0	23.4	10.1	1.9	1.0	472
1967	23.5	18.4	23.4	12.7	1.8	1.0	490
1968	22.6	18.7	23.7	12.7	1.9	1.0	528
1969	22.5	18.8	23.2	14.4	1.6	0.9	570
1970	20.1	18.4	23.1	15.7	1.9	0.9	595
1971	18.8	17.8	22.0	15.2	1.9	0.9	582
1972	19.2	18.0	22.1	15.4	1.9	0.8	629
1973	19.6	17.6	21.6	17.1	1.9	0.8	696

Source: Svensk Järnstatistik 1971, 1972, 1973 (Jernkontoret 1972, 1973, 1974), tabell 17.

Table 6:4. Size distribution of the Swedish steel plants in 1968 and 1973

Annual production capacity 10^3 tons	Total Number		Included in the study Number		
	1968	1973	1968	1973	
< 25	7	3	3	2	1
26- 75	7	8	5	5	3
76- 300	14	14	13	11	3
301- 500	-	3	-	3	
501-1,000	2	1	2	1	
>1,000	1	2	1	2	
	31	31	24	24	

The fact that Swedish steel plants are small by international standards can partly be explained by the relatively large number of plants producing so-called special steel. As pointed out above, approximately 26 % of Swedish steel production in 1968 consisted of special steel. The share of special steel was around 7-8 % in the European Community countries and approximately 10 % in the U.S. and Japan in the same year.

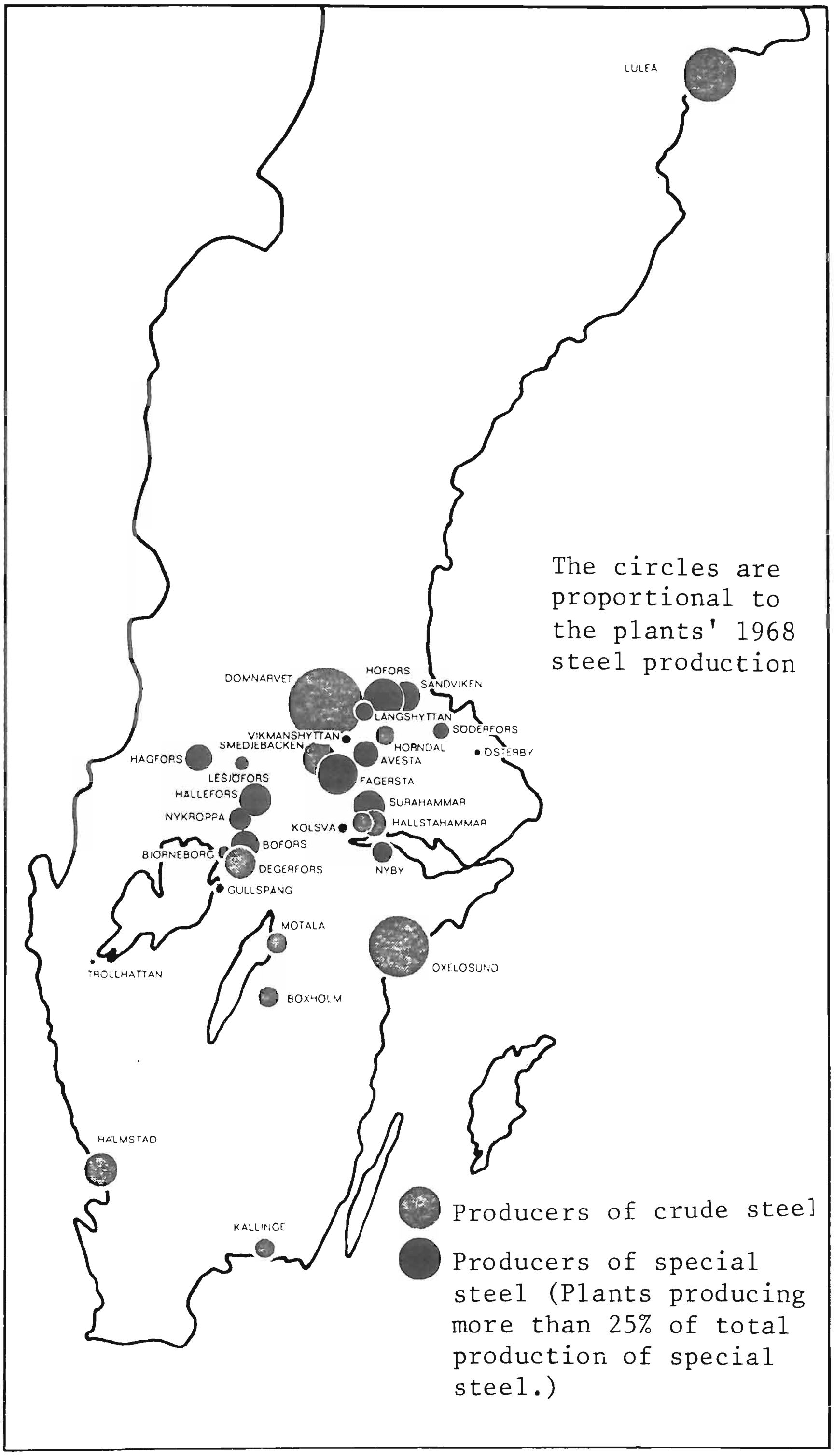
The geographical distribution of the Swedish steel plants can largely be historically explained. The majority of the existing plants were established during a period when proximity to raw materials (i.e. forests and ore) was of decisive importance for the location of a steelplant. This is of course no longer a major constraint on the location of a steelplant and the three major plants established during the last 50 years (i.e. Oxelösund, Luleå and Halmstad) are all located on the coast. There is, however, still a concentration of steel plants in the central part of Sweden and 24 out of 31 plants are located in what is known as the "Bergslagen". The location of the Swedish steelplants is shown in Figure 6:2.

In view of the fact that the Swedish iron and steel industry is small by international standards and that its structure differs substantially from that of other countries, it is difficult to draw general conclusions from an analysis of aggregated data. As pointed out in Chapter 3, this problem can partly be overcome by an analysis at a disaggregated level - i.e. by studying various subprocesses separately rather than the production process as a whole. Consequently, this is the methodology that will be followed in sections 2 and 3 of this chapter.

6.1.3 Size of total emissions

The 1969 enactment of a comprehensive legislation for environmental quality protection (i.e. the Environment Protection Act) reflected a recognition of the fact that unlimited discharges of residuals might cause severe (and sometimes unlimited) damage to the environment. Even though previous legislation in the field of environmental protection called for some emission control measures in most industries, these measures were, in general, quite unsatisfactory from an environmental point of view. In the discussions preceding the enactment of the EPA,

Figure 6:2. Geographical distribution of the Swedish iron and steel industry



The circles are proportional to the plants' 1968 steel production

● Producers of crude steel

● Producers of special steel (Plants producing more than 25% of total production of special steel.)

Source: Svensk stålindustri inför 1970-talet. Stockholm 1969 (p.35).

the need for a quick "clean-up" of existing plants was often emphasized. The government subsidization scheme set up in conjunction with the enactment of the EPA, must, therefore, be seen against that background. In order to give an idea of the dimension of the problem and the size of the efforts made during the period under investigation, the total level of emissions 1969 and 1973 are presented for three of the most inportant residuals from the iron and steel industry (Table 6:5). Section 3 of this chapter is devoted to a study of the costs of achieving these discharge reductions.

Table 6:5. Annual emissions of particulates, SO_2, and suspended solids from the iron and steel industry 1969 and 1973

Type of residual	Emissions 1969 10^3 tons/year	Emissions 1973 10^3 tons/year	Reduction 1969-73 10^3 tons/year
Particulates	57	4	53
SO_2	62	60	2
Suspended solids	43	12	31

+576 tn.

6.2 TECHNICAL CHARACTERISTICS OF IRON AND STEEL PRODUCTION

In the context of economic analysis the definition of iron differs from the one used in chemistry. Chemically pure iron is rarely found in nature and is also of limited importance for industrial purposes.

Iron for industrial use generally contains a number of materials besides pure iron. These materials can either be added on purpose (in which case they are called alloys) or be regarded as impurities originating from the raw materials or the processing operations. In most qualities of industrial iron small amounts of carbon, silicon, and manganese remain. Materials like phosphor, sulphur, hydrogen, copper, zink, tin and oxygen are generally regarded as undesired elements, i.e. impurities. Various types of special steels are produced by adding alloy materials like chromium, nickel, wolfram, molybden, cobolt, vanadium, titanium, aluminium, lead, nitrogen, copper, niob, and bor.

Depending upon whether the carbon content is lower or higher than 2 %, chemical associations between iron and carbon are classified as steel or cast iron. Steel, in turn, can be classified as either unalloyed steel (carbon steel) or alloyed steel.

6.2.1 General description of production processes

The transformation of iron ore into a form which can be used for industrial purposes takes place in a number of distinctly different processing steps. The four principal steps are: (1) Preparation of raw materials, (2) Raw iron manufacturing, (3) Raw steel manufacturing, and (4) Finishing of steel products. The various components of these processing steps are shown in Figure 6:3.

6.2.1.1 Preparation of raw materials

The first step can be divided into three subprocesses, namely (a) ore preparation (which is generally carried out at the mine), (b) coking, and (c) sintering.

The coke, which is used as fuel and reactive agent in the raw iron manufacturing process (blast furnace), is produced by heating coal in the absence of air to a temperature at which the major part of the non-carbon components of the coal (i.e. volatile matter, water, and sulphur) are driven off. Since approximately 25 % of the coal is carburated during the coking process, large amounts of gas (4-5,000 Nm^3/ton of coke) are generated. In the most common method of manufacturing metallurgical coke, the by-product coking process, the coke oven gas is treated in order to remove by-products (e.g. tar, ammonia, sulphur, light oil, and phenol).1) The treated coke oven gas is either used elsewhere in the plant as fuel or sold as town gas.

In the sintering process, the fine ore particles are agglomerated into a porous mass that can be charged into the blast furnace. The purpose of the sintering is, apart from an agglomeration of the ore con-

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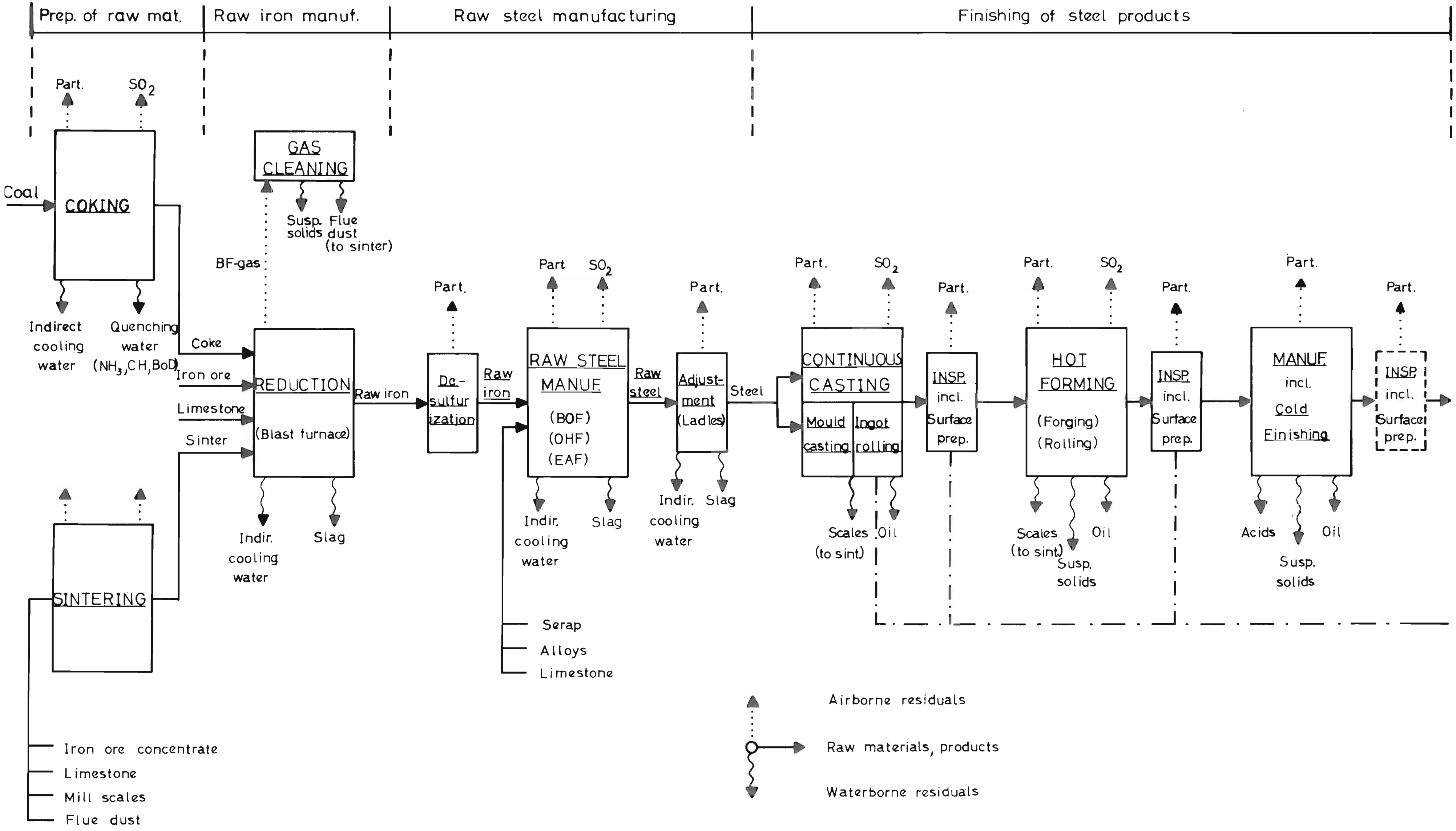
1) The recovery of chemicals from ghe gases was previously of central importance for the profitability of coke and gas manufacturing. After World War II, prices on these products have decreased to such an extent that the recovery units today are motivated primarily by environmental quality concerns.

Figure 6:3. Principal processing steps of iron and steel production.



centrate, to burn some of the sulphur compounds contained by the ore concentrate. The sintering machine is charged with a mixture of iron ore concentrate, coke dust, and limestone which is lit by gas flames. In order to get the high temperature necessary for the agglomeration to take place, air is sucked through the mixture by the help of large fans.

6.2.1.2 Raw iron manufacturing

The primary raw material for raw iron manufacturing is sinter. Each ton of raw iron requires approximately 1.6 tons of sinter. Sinter contains iron primarily in the form of iron oxide and in order to get raw iron, the iron oxide must be reduced. This reduction is accomplished under high temperature in the blast furnace. The carbon needed for the reduction is added in the form of coke.2) In order to attain the temperature necessary for the reduction of the iron oxide and the melting of the metallic iron, air is blown through the furnace.

One of the major impurities in the iron ore (and in the coke) is silica (SiO_2). This mineral has a very high melting point and if some method of removing the silica from the furnace were not provided, the furnace would rapidly fill up with ashes and become inoperative. This is prevented by the addition of limestone since, at the high temperature of the furnace, the lime combines with the silica to form a low melting material called slag. The molten slag is lighter than the melted iron and, therefore, floats on top of the iron. As the iron is tapped from the bottom of the furnace, the floating slag is skimmed off. Molten iron and slag is drawn off from the furnace 5-6 times each day. Depending upon their size, blast furnaces will produce from a few hundred to five thousand tons of raw iron per day.

What happens inside the blast furnace during the manufacturing cycle is that when air (preheated to approximately 1,000°C) is blown through the furnace from the bottom, the coke burns and forms carbon monoxide gas which passes through the furnace. This carbon monoxide is the active agent in the process since it can combine with oxygen. Part of the carbon monoxide generated combines with the oxygen of the

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2) For Swedish blast furnaces, the coke requirements per ton of raw iron have been estimated to approximately 0.45 tons.

iron oxide and forms carbon dioxide. The gas leaving the top of the blast furnace consists of carbon monoxide (25-30 %), carbon dioxide (17-19 %), hydrogen (1 %), and nitrogen (58 %). Since this combustible gas has a high load of particulates, it must be cleaned before it can be used as fuel elsewhere in the plant. Cleaning of the blast furnace gas is therefore considered a normal part of the raw iron manufacturing process.

The use of coke as fuel and reducing agent in the blast furnaces generally leads to a quite high content of sulphur in the pig iron. For pig iron that is to be used for the production of so-called special steel, this is an undesirable property. In order to reduce the sulphur content of raw iron intended for such use, the raw iron is desulphurized with burned lime in ladles.

6.2.1.3 Raw steel manufacturing

The molten iron leaving the blast furnace has a high content of carbon (3-4.5 %) and also contains undesirable amounts of silicon, manganese, and phosphorous. The process of steel manufacturing aims at oxidizing these materials and reducing the carbon content to between 1.7 and 0.03 %. For the different grades of steel there are specifications for the content of carbon as well as the concentration of various "impurities". In the production of special steels, various alloy elements that contribute to the desired properties of the steel are added.

The three types of steel furnaces in common use today are: (a) The open hearth furnaces, (b) The basic oxygen furnace, and (c) The electric arc furnace. For production of alloyed steel of extra high quality, so-called high-frequency furnaces (or induction furnaces) are also used.

(a) The open hearth furnace process

Steelmaking in an open hearth furnace is a relatively old method of production. The furnace consists of a rather shallow, refractory lined, rectangular room with openings at both ends. These openings are interchangeably used for injection of preheated air and evacuation of exhaust gases. Adjacent to these openings are either fuel oil burners or inlet pipes for combustible gas. Underneath the furnace there are four brick-filled chambers for preheating of air and (in some cases) gas.

During the steelmaking cycle, preheated air together with fuel is blown into the furnace from one end for approximately 15 minutes. The exhaust gases leave at the other end of the furnace and are led through two of the brick chambers where they heat the bricks. After 15 minutes the direction of the flow is reversed and the heat of the bricks is now used for preheating the incoming air. These changes of flow directions are continued through the whole steelmaking cycle.

In order to accomplish the desired degree of oxidation it is necessary to have a high temperature (1,600°C) in the furnace. Since the open hearth furnace steelmaking cycle is relatively timeconsuming (12-14 hours) compared with other steelmaking processes, oxigen is often blown into the steel bath with a lance for 15-90 minutes in order to reduce the cycle-time. The oxygen accomplishes three things, namely: (1) reduces the melting time, (2) increases the temperature, and (3) raises the rate of oxidation. With the use of oxygen the tap-to-tap cycle time can be reduced to between 5 and 8 hours.

Depending upon the chemical composition of the material with which the furnace is lined, one talks about the acid or the basic open hearth furnace steelmaking process. Characteristic for both processes is the high proportion of steel scrap in the charge. For the acid process, however, it is necessary to use high quality steel scrap (i.e. primarily internal steel scrap) and pig iron with very low phosphor and sulphur content. The basic process is somewhat less sensitive to the composition of the charge. Like in other basic steelmaking processes, however, limestone has to be added to facilitate slag formation.

(b) The basic oxygen furnace process

In the basic oxygen furnace process a charge of melted pig iron and steel scrap is blown with pure oxygen, introduced through a water cooled lance. The converter can be either stationary (the LD process) or rotating (the Kaldo process). Unlike the open hearth and the electric arc furnace processes, no supplementary heat source is provided. The only sources of heat are the heat in the hot metal and the heat generated by the reactions between the oxygen and metalloids in the hot metal. The Kaldo process has a somewhat better heat economy than the LD process which allows it to use a higher proportion of scrap. The Kaldo process can also use pig iron with a relatively high phosphorous content, something which is not possible in the LD process. However, the LD process has a somewhat shorter tap-to-tap cycle time than the Kaldo process (approximately 1 hr vs. 2 hrs).

(c) The electric arc furnace process
In the third method of steel manufacturing, the electric arc furnace process, a cold charge of steel scrap is melted and refined with electric power as the source of heat. Graphite electrodes positioned above the cold charge transmit current through the charge, so that the heat developed by the electrical resistance of the metal in combination with the heat radiated from the electric arc melts the charge. In the operating of the electric arc furnace, fluxing materials are added to the charge so that a slag is produced just as in the other basic furnace operations.

The electric arc furnace process can either be used to produce the common grades of low-carbon steel from scrap or be charged with alloying materials to produce special steels such as stainless steel or tool steel. Electric furnaces are also used for production of the ferro-alloys which are the alloying elements for these special steels. In order to reduce the process time (2-4 hrs), oxygen can be lanced through the bath during a period of 15-30 minutes.

The raw steel coming from the steel furnaces generally needs a final adjustment (or refining) in order to meet quality specifications. The main refining reaction at this stage is degassing which is generally carried out under vacuum. For this reaction stirring is of great importance. The stirring energy needed for equalization of the bath is quite small and can be supplied by gas purging, mechanical means, or by induction.

6.2.1.4 Finishing of steel products

The conversion of raw steel from the steel furnaces into products ready for industrial use takes place in three principal steps, namely: (a) Casting, (b) Hot forming, and (c) Manufacturing.

(a) Casting
The most common method of preparation of molten raw steel for further processing has long been to pour the steel into ingot molds, allowing

the steel to cool and solidify. After cooling the ingots are removed from the molds and transferred to the primary forming (rolling) units for a preparation into semi-finished products like billets, blooms, and slabs.

In a newer process called continuous casting, the molten steel is directed into water-cooled, open-ended copper molds. As the steel passes through the copper mold, the surface cools and forms a hard steel shell with a liquid center. As the shape (billet, bloom, or slab) emerges from the mold, it enters a spray area where water is sprayed on the steel to cool it further. The steel slab, bloom, or billet then passes a cutoff point where it is cut to the desired length. By eliminating ingots, soaking pits, mold preparation, and stripping facilities, the method of continuous casting substantially reduces the generation of airborne residuals.

After the casting step, the semi-finished shapes usually pass an inspection stage. In most cases the inspection is combined with some kind of surface preparation. At this stage of the production process, the surface preparation generally consists of various mechanical, physical, or chemical operations. The mechanical operations include such measures as grinding, blasting, and polishing. Among the physical operations hot dipping, thermal spraying, and flame scarfing are the most commonly used. Pickling is the most widely used of the chemical operations for surface preparation.

(b) Hot forming

After the semi-finished shapes have been reheated to ensure uniform temperature, they are further processed in the hot forming shops of the plant.

The hot rolling operation consists of the gradual compression of the shape between the surfaces of rotating rolls, and the progression of the shape through the space between the rolls. After passing through a series of forming, reducing, and scale breaking operations, the shape moves to the finishing stands for the final size reduction. High pressure water is used to remove scale, and spray-water may be applied on the run-out table for cooling purposes.

The forging process produces a shape that closely resembles the finished product. Forging could be described as the hot forming of steel between flat or contoured dies. The work performed on the steel in the forging process results in products that have the desired mechanical and metallurgical properties as well as the desired size and shape.

The extrusion process, finally, is used where it is difficult to produce shapes by other processes. Hot extrusion consists of enclosing a heated piece of metal in a chamber having a die at one end with an opening of the shape of the desired finished section, and applying pressure to the plastic metal through the opposite end of the chamber. This process gives a product well suited for cold drawing and machine processing.

The hot forming process is generally also terminated by an inspection and surface preparation stage where various mechanical, physical, and chemical operations are applied to the semi-finished products.

(c) Manufacturing

The final step in the process of finishing the steel products is generally referred to as the manufacturing stage. In this stage, the semi-finished steel products are subjected to a number of different processing operations aimed at giving the products certain desired properties. The most important among these operations are cold rolling, wire drawing, and pressing. Various forms of surface preparation is quite frequently also included in this processing step. Apart from the usual mechanical, physical, and chemical operations, surface preparation in the manufacturing step sometimes also include electrolytical operations and/or application of non-metallic coatings (i.e. paints, enamels, plastic, etc.) by means of dipping, painting, or spraying.

6.2.2 Raw residual loads in the Swedish iron and steel industry

As indicated in Figure 6:3, various kinds of residuals are generated at each step of the production process. The types and amounts of residuals generated at the various processing steps depend upon a number of factors of which the quality of the raw materials, the type of production equipment, and the type of final product are among the most important. Consequently, it is not possible to express the raw residual loads from the different operations in representative single figures.

For some operations there are, in fact, substantial variations in the amounts of residuals generated per ton of output. In order, then, to avoid giving an apparently precise (but unrepresentative) picture of the raw residual loads of iron and steel production, the range of variation of the residual loads in the observed Swedish plants is used. As a frame of reference for the further analysis, however, median raw residual loads are also given in the summary table (Table 6:5).

6.2.2.1 Preparation of raw materials

The coking process generates a number of airborne, waterborne, and solid residuals. The principal sources of airborne residuals are the coal and coke handling operations, the charging and discharging of the ovens, and the burning of the coke in the ovens. Approximately 70 % of the airborne residuals (apart from SO_2) generated at a coke plant originates from the charging of the ovens. The range of variation for the raw loads of airborne residuals from a coke plant are for particulates 0.5-3.5 kg/ton of coke, for sulphur dioxide 0.2-1.0 kg/ton, for hydrocarbons 0.2-0.8 kg/ton, and for hydrogen cyanide 0.1-0.6 kg/ton.

The most significant waterborne residuals generated at a coke plant originate from the coke quenching and from the gas cleaning in the by-product plant. For a coke plant as a whole, the range of variation of the raw loads of some of the major waterborne residuals are as follows: ammonia 0.3-10 kg/ton, suspended solids 0.2-15 kg/ton, phenols 0.7-5 kg/ton, sulphide 0.8-2.5 kg/ton, cyanide 0.4-5 kg/ton, and BOD_7 2.4-6 kg/ton.

The residuals generated during the sintering process are primarily particulates and sulphur dioxide. The sulphur dioxide is generated in the sintering furnace and originates from the sulphur in the iron ore concentrate and the coke dust. If oil is used as fuel in the furnace, the amount of SO_2 generated will be correspondingly higher. The range of variation for the raw loads of sulphur dioxide is 1.0-8.0 kg/ton of sinter. The particulates generated during the sintering process originate primarily from the sintering furnace and from the raw materials and sinter handling stations (80 %). The raw loads of particulates generated in the sintering process generally vary between 15 and 25 kg/ton of sinter.

6.2.2.2 Raw iron manufacturing

The cleaning of the blast furnace gas (which is a normal part of the raw iron manufacturing process) means that under ordinary operating conditions negligible amounts of airborne residuals are emitted through that gas stream. Thus, the only airborne residuals in connection with raw iron manufacturing are the particulates from the tapping operation. The range of variation for the raw load of this residual is 0.1-0.6 kg/ton. From the desulphurization ladles (which should, perhaps, be regarded as part of the raw <u>steel</u> manufacturing step rather than the raw <u>iron</u> manufacturing step) the raw load of particulates amounts to between 0.1 and 1.0 kg/ton.

The water used for gas cleaning purposes generally contains 1.0-5.0 kg/ton of suspended solids, 0.3-0.4 kg/ton of sulphide, 0.1-0.2 kg/ton of ammonia, less than 0.1 kg/ton of flouride, and less than 0.05 kg/ton of cyanide and phenol. The pH of the gas cleaning water ranges between 7 and 11.

The large quantity of slag produced in the blast furnace (200-240 kg/ton) is generally granulated before final disposal. The water used in connection with slag granulation is also contaminated with suspended solids and various chemical compounds. The amount of suspended solids varies between 1-2 kg/ton of raw iron and the amount of chlorides between 0.3 and 0.8 kg/ton. This water generally also contains between 0.3 and 0.4 kg/ton of sulphates and less than 0.1 kg/ton of hydrogen sulphide.

Since blast furnaces are generally quite large and operate at high temperatures, large volumes of cooling water are normally required. Most plants use once-through cooling systems, although recirculation of cooling water is practiced in some areas with limited water supplies. The temperature rise of the cooling water is quite moderate, however, and rarely exceeds 5°C.

Since dry cyclones are generally used as a first step of the gas cleaning process, 20-30 kg particulates per ton of iron are generated as a dry solid residual.

6.2.2.3 Raw steel manufacturing

(a) The open hearth furnace process

The principal airborne residuals generated during the process of steelmaking in open hearth furnaces are:

(1) dust and grit from handling of raw materials, refractories, and slag;

(2) particulates (primarily iron, zinc, lead, and manganese oxides) from the oxidation in the furnace;

(3) sulphur dioxide from the burning of the fuel in the furnace.

The airborne residuals generated by the raw materials handling are generally quite difficult to collect and treat in an economically feasible way. However, since the amounts of residuals generated by these processes are small compared to the amounts generated in the furnace, low priority is generally given to the reduction of the latter of these emissions.

The amount of particulates produced in the furnace during the steelmaking cycle depends strongly on whether oxygen is used or not. According to existing studies, the amount of particulates generated varies between 2 and 5 kg/ton steel (without oxygen) and between 5 and 20 kg/ton steel (with oxygen). The use of oxygen also reduces the size of the particles so that most of the particles will be smaller than 0.1 µm. During the oxygen blowing, the concentration of particulates in the exhaust gas is 3-4 times higher than during the rest of the steelmaking cycle.

The sulphur dioxide in the gases originates from the sulphur of the fuel oil used in the furnace. In order to prevent sulphur from combining with the steel and the slag, it is common practice, at least among Swedish OHF steel producers, to use low-sulphur fuel oil (i.e. $S < 0.5$ %) during the melting phase. On the average, 90-95 liters of fuel oil per ton of steel is used in an open hearth furnace process, and the amount of SO_2 generated varies between 0.7 and 6.0 kg/ton. The slag formation during the process varies between 45 and 100 kg/ton with oxygen blowing, and between 90 and 120 kg/ton without.

Open hearth furnaces also use large quantities of water for cooling. This water generally does not contain any significant amounts of residuals.

(b) The basic oxygen furnace process

The generation of residuals in the BOF process is mainly due to the practice of blowing pure oxygen into the furnace. Because of the high temperature formed in the area where the oxygen is penetrating the bath surface, iron is directly oxidized to a fine iron oxide dust. Since lime is used as a flux in different amounts (depending upon the not metal composition and the ratio of hot metal to cooling agents, i.e. scrap or iron ore) some lime dust is also blown out of the furnace with the exhaust gases. The lime dust is primarily found during the first phase of oxygen blowing. During the later phases, the gases contain mostly particles of iron and manganese oxide. Analyses of the chemical composition of the dust show that approximately 90 % of it consists of iron oxide. The size of the particles is quite small, with 85 % of the grains being smaller than 1.0 µm and 50 % smaller than 0.5 µm. The range of variation of the raw loads of particulates generated in BOF steelmaking process is 30-33 kg/ton. As far as SO_2 is concerned, there are no such emissions from the BOF process. The raw loads of slag from the furnaces vary between 85 and 205 kg/ton of steel.

The water requirements of the BOF process itself refer to cooling only. Since the cooling water for the furnaces generally flows in closed systems, this water will not be contaminated with any residuals.

(c) The electric arc furnace process

The high pressure generated in the furnace when the charge is being heated, melted, and refined causes the emission of fine particulates through openings around electrodes, spouts, doors etc. Emissions also take place when the furnace is opened for charging or tilted for tapping. The amounts and types of particulates produced by the process of steelmaking in electric arc furnaces depend upon factors such as the composition of the charge (i.e. the proportion of oxidized and oily materials), the melting rate, the furnace temperature, the physical state of the fluxing agent, and the extent to which oxygen lancing is used. The amounts of particulates generated also vary during the different stages of the process. The rate of emission is greatest during oxygen lancing and the melting phase. It is estimated that approximately 75 % of all emissions take place during the first half of the process cycle. The raw load of particulates generated by the electric arc furnace process varies from 3 to 8 kg/ton of steel without oxygen lancing and from 5 to 15 kg/ton of steel with oxygen lancing.

The size of the particles varies between 0.1 µm and 2.0 µm with 95 % of the particles < 0.5 µm. Around 60 % of the dust consists of iron oxide whereas the concentration of magnesium oxide is around 10 %. This dust is generally disposed of by using it as land fill. There are at present programs in progress to determine whether or not this dust (with its high metallic content) can be reused. The concentration of sulphur dioxide in the exhaust gases is generally quite low and the raw load is in the range 0.1-1 kg/ton. The amount of slag generated in the EAF varies between 65 and 90 kg/ton of steel. The cooling water for the EAF does generally not contain any residuals.

(d) Adjustment of raw steel

The range of variation of the raw loads of particulates generated during the adjustment of the raw steel is quite large. Depending upon the adjustment technology used, the raw loads can be as low as 0.1 kg/ton and as high as 16.0 kg/ton of steel. Slag formulation amounts to 40-60 kg/ton.

6.2.2.4 Finishing of steel products

(a) Casting

(a.1) Mold casting

The large amount of particulates generated in the mold casting process originates in the mold preparation stage, during the casting, and in the stripping stage. The range of variation for this residual load is 10-35 kg/ton ingot. During the reheating of the ingots before the primary rolling, sulphur dioxide is generated in amounts varying between 0.5 and 7.0 kg/ton.

(a.2) Continuous casting

The continuous casting method does not produce airborne residuals to the same extent as the mold casting method. By eliminating the molding, pouring, stripping, and ingot reheating operations, the amounts of particulates and sulphur dioxide generated are quite insignificant.

The waterborne residuals associated with continuous casting are BOD_7 (0.6-1.6 kg/ton), oil (0.9-1.0 kg/ton). suspended solids (0.3-2.5

kg/ton).[3]

(b) Hot forming

(b.1) Forging

The amounts of airborne residuals generated in the forging process are for particulates 0.5-3.5 kg/ton and for sulphur dioxide between 1.0 and 4.0 kg/ton. The waterborne residuals consist primarily of oil (1.0-2.0 kg/ton) and suspended solids (0.5-1.0 kg/ton). In addition to these air- and waterborne residuals, 8-10 kg of solid residuals (scales) are generated per ton of forged steel.

(b.2) Rolling

The rolling mills are relatively unimportant as sources of airborne residuals. Thus, the amount of particulates generated varies between 0.4 and 1.0 kg/ton and the amount of sulphur dioxide between 1.0 and 4.0 kg/ton. These residuals originate primarily in the fuel oil used in the heating furnaces.

The water used for cooling the rollers and bearings, for washing, and for scaling in the hot rolling mills account for about 70 % of the waste water of an integrated iron and steel mill. After sedimentation of the larger particles (scales) in scale pits (approximately 15-35 kg/ton) this water still contains suspended solids in an amount of 0.5-4.0 kg/ton of rolled steel. The content of oil (resulting from the washing off of the lubricants during cooling of the rollers) in the waste water ranges between 0.2 and 0.5 kg/ton.[4]

(c) Manufacturing

The airborne residuals associated with the manufacturing of steel products are primarily generated by the various mechanical surface preparation operations (i.e. grinding, blasting, polishing, etc.) and the raw load of particulates varies between 2 and 16 kg/ton. The amount of solid residuals (grindings) generally varies from 5 to 15 kg/ton.

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[3] If the primary rolling step is included in the mold casting process, the generation of waterborne residuals will be 5-10 % higher than in the continuous casting process.

[4] The sedimentation of scales in scale pits is a normal part of the rolling process. The recovered scales are generally returned to the sintering plant for reprocessing.

The major part of the waterborne residuals generated in the manufacturing stage originates in the chemical and the electrolytical operations. The pickling processes generate two types of waste water: (1) depleted pickling-tank solutions which have lost their pickling properties, and (2) rinsing water from washing of the metal. The amounts of residuals in the waste water are for suspended solids 0.1-0.4 kg/ton of pickled steel, for total iron 2-22 kg/ton, for sulphates (SO_4^-) 4-40 kg/ton, for chlorides Cl^-) < 0.3 kg/ton, for zink (from galvanizing operations) 0.4-0.5 kg/ton, and for acids (primarily sulphuric and hydrochloric acid) 1-27 kg/ton of pickled steel.

6.2.2.5 Service operations

Service units like power plant boilers and raw materials handling stations are also sources of airborne residuals like particulates and sulphur dioxide. The range of variation for the raw loads of particulates from boilers is 0.4-1.0 kg/ton steel and for sulphur dioxide 1.0-4.0 kg/ton. The diffuse dusting originating in the handling of raw materials (coal, coke, limestone, sinter, etc.) is difficult to measure (as well as to treat) but is estimated to amount to 1-3 kg/ton of material handled.

6.2.2.6 Summary

A summary presentation of the raw residual loads in the iron and steel industry is given in Table 6:6. The range of variation given for the raw loads of the most important residuals refers, as pointed out in the beginning of this section, to Swedish iron and steel production in general. The figures within brackets are the median values.

6.2.3 Base level of emission control in the Swedish iron and steel industry

Since environmental quality control is not an entirely new thing and some regulations concerning discharges of residuals were in force before July 1, 1969 (when the Environment Protection Act came into force) most iron and steel plants had some emission control equipment in operation before that date. In order to be able to determine the effects

Table 6:6. Range of variation for raw residuals load from iron and steel production (kg/ton)
(Figures within brackets are median raw residual loads in the Swedish iron and steel industry)

Sub-processes	Processing technology	Waterborne residual													Airborne residual					Solids			
		BOD_7	Susp. solids		Metals	Acids	Oil	Amm. (NH_3)	Phenols	Sulfides	Cyanide	Chlor (Cl^-)	Sulfates	Zinc	Particl.	SO_2	Hydro-carbons	Sulfur comp.	Other	Slag	Sludge	Solids	
Coking	By-prod. coking	2.4-6.0 (n.a.)	0.2-15.0 (0.5)					0.3-10 (0.3)	0.7-5.0 (0.7)	0.8-2.5 (n.a.)	0.4-5.0 (n.a.)				5-15 (8.7)	0.2-1.0 (0.9)	4-8 (5.6)		0.1-0.6* (0.1)				*Hydrogen cyanide
Sintering															15-25 (16.5)	1.0-12.0 (2.0)							
Raw iron manufacturing	Blast furnace		2.0-7.0 (3.4)					0.1-0.2 (0.2)	··· (···)	0.4-0.5 (0.4)	··· (···)	0.3-0.8 (0.3)	0.3-04 (n.a.)		0.2-1.6 (0.8)					200-240 (220)		20-30 (24)	Gas cleaning part of process
Raw steel manufacturing	Basic oxygen furnace (LD)														30-33 (30.0)					120-205 (120)			
	Basic oxygen f. (Kaldo)														30-50 (33.0)					85-205 (200)			
	Open hearth furnace														2-20 (3.8)	0.7-6.0 (1.4)				45-120 (100)			Without 0_2: 2-5 kg/t With 0_2: 5-20 kg/t
	Electric arc furnace														3-20 (5.7)	0.1-1.0 (0.1)				65-90 (90)			Without 0_2: 3-8 kg/t With 0_2: 5-20 kg/t
Adjustment of raw steel	Ladles														0.1-16.0 (9.8)					40-60 (50)			
Casting	Mold casting	0.7-1.7 (0.9)	0.3-2.5 (2.4)				1.0-1.1 (1.0)	< 0.8 (···)	< 0.3 (···)						10-75 (20.0)	0.5-7.0 (3.0)						200-220 (210)	Waterborne res. from prim. rolling
	Continued casting	0.6-1.6 (0.8)	0.3-2.5 (2.4)				0.9-1.0 (0.9)	< 0.7 (···)	< 0.3 (··)													170-190 (180)	
Hot forming	Rolling		0.5-4.0 (1.0)				0.2-0.5 (0.2)								0.4-1.0 (0.4)	1.0-4.0 (2.0)						15-35 (22)	Scale recovery part of process
	Forging		0.5-1.0 (0.5)				1.0-2.0 (1.0)								0.5-3.5 (1.0)	1.0-4.0 (3.0)						8-10 (8)	
Manufacturing	Surface preparation		0.1-0.4 (0.4)		2-22 (7.7)	1-27 (6.5)						< 0.3 (···)	4-40 (n.a.)	0.4-0.5 (0.4)	2-16 (5.0)							5-15 (10)	
Service	Raw materials handling														10-30 (1.6)								
	Generation of heat														0.4-1.0 (0.5)	1.0-4.0 (4.0)							

Abbreviations: n.a. = information not available: ··· = traces.

on discharges of the environmental policy pursued between July 1, 1969 and July 1, 1973 it is necessary to specify the level of emission control at the beginning and at the end of this period.

A short discription of the technical efficiency of the residuals treatment equipment in existence at the beginning of this period is presented below.

6.2.3.1 Preparation of raw materials

In order to reduce particulate emissions from the charging of the coke ovens, the single Swedish coke plant had installed equipment for so-called "direct gas extraction". By this method the emissions of particulates were reduced by approximately 90 % or from 8.9 kg/ton of coke to 1.0 kg/ton, and the emission of hydrocarbons by 95 % (i.e. from 5.6 to 0.3 kg/ton).

The waterborne residuals generated by the gas cleaning operations were not subjected to any treatment before discharge.

All sintering plants were using dust catchers and/or cyclones for controlling the emissions of particulates. The efficiency of collection varied between 80 and 97 % and the median discharge per ton of sinter was 2.5 kg/ton. This should be compared with the median raw residual load of 16.5 kg/ton.

6.2.3.2 Raw iron manufacturing

Since cleaning of the blast furnace gas is a normal part of the raw iron manufacturing process, the residuals generated by this part of production process are primarily waterborne chemical compounds and slag. By July 1, 1969, only one plant was equipped with equipment for treatment of the waterborne residuals from the gas cleaning. By the use of a sedimentation basin this plant reduced its discharges of suspended solids by approximately 25 %.

6.2.3.3 Raw steel manufacturing

By July 1, 1969, none of the existing open hearth furnaces was equipped with residuals treatment equipment. Consequently, emissions from this type of steel furnaces were identical with the raw residual load, i.e. 3.8 kg/ton particulates and 1.4 kg of SO_2 per ton of steel.

The basic oxygen furnaces, on the other hand, were all equipped with electrostatic precipitators having an average efficiency of over 99 %. However, since some gases escape through roof lanterns, the particulates emissions from the basic oxygen furnaces were actually reduced from a potential 33.0 kg/ton to 1.3 kg/ton of steel, i.e. by roughly 96 %.

Only about 15 % of the electric arc furnaces were connected to any emission control equipment. In all of the cases, the type of equipment used was venturi scrubbers. The particulates emissions from these furnaces after treatment were 1.5 kg/ton of steel. The median level of emissions from electric arc furnaces was 4.9 kg/ton.

In most of the plants where electric arc furnaces were equipped with venturi scrubbers, sedimentation of the scrubber water was also practiced.

6.2.3.4 Finishing of steel products

Most of the casting shops had some equipment for treatment of airborne residuals installed. The types of equipment most commonly used were cyclones and scrubbers. The median emissions of particulates from the casting operations amounted to 2.0 kg/ton. In the shops for mechanical surface preparation, cyclones were in common use, and the median discharge of particulates after treatment was 0.2 kg/ton.

Apart from the recovery of scales, the waterborne residuals generated in the finishing section of the production process were generally not subjected to any treatment. Only very few plants were operating equipment for reduction of the discharges of oil and emulsions or for the neutralization or regeneration of spent pickling liquor.

6.2.3.5 Summary

In Table 6:7, the median levels of residuals discharges from the Swedish iron and steel industry by July 1, 1969 are presented. The percentage discharge reduction (in comparison to raw residual loads) implied by these emission levels is also indicated in the table.5)

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5) In this context it must be emphasized that the median levels of raw residual loads and discharges refer to normal operating conditions. Malfunctions or breakdowns of processing or treatment equipment could temporarily raise raw residual loads and discharges to levels several times those indicated in Tables 6:7 and 6:9.

Table 6:7. Median levels of residuals discharges from Swedish iron and steel plants (kg/ton)

(Figures within brackets indicate percentage reduction of discharges in comparison with median raw residual loads)

Sub-process	Processing technology	Waterborne residuals													Airborne residuals					Solids			
		BOD_7	Susp. solids		Metals	Acids	Oil	Amm. (NH_3)	Phe-nols	Sul-fides	Cya nide	Chlor. (Cl^-)	Sul-fates	Zink	Par-ticl.	SO_2	Hydro-carbons	Sulfur comp.	Other	Slag	Sludge	Solids	
COKING	By-prod. coking	n.a.	0.5 (–)					0.3 (–)	0.7 (–)	n.a.	n.a.				1.0 (89%)	0.9 (–)	0.3 (95%)		0.1* (–)				*Hydrogen cyanide
SINTERING															2.5 (85%)	2.0 (–)							
RAW IRON MANUFACTURING	Blast furnace		3.4 (–)					0.2 (–)	··· (–)	0.4 (–)	··· (–)	0.3 (–)	n.a.		0.8 (–)					220		24	Gas cleaning part of process
RAW STEEL MANUFACTURING	Basic oxygen f. (LD)														1.3 (96%)					120			
	Basic oxygen f. (Kaldo)														1.3 (96%)					200			
	Open hearth f.														3.8 (–)	1.4 (–)				100			Without 0_2: 2-5 kg/t With 0_2: 5-20 kg/t
	Electric arc f														4.9 (14%)	0.1 (–)				90			Without 0_2: 3-8 kg/t With 0_2: 5-20 kg/t
ADJUSTMENT OF RAW STEEL	Ladles														9.8 (–)					50			
CASTING	Mold casting	0.9 (–)	2.4 (–)				1.0 (–)	··· (–)	··· (–)						2.0 (90%)	3.0 (–)						210	Waterborne res. from prim rolling
	Continuous c.	0.8 (–)	2.4 (–)				0.9 (–)	··· (–)	··· (–)													180	
HOT FORMING	Rolling		1.0 (–)				0.2 (–)								0.4 (–)	2.0 (–)						22	Scale recovery part of process
	Forging		0.5 (–)				1.0 (–)								1.0 (–)	3.0 (–)						8	
MANUFACTURING	Surface preparation		0.4 (–)		7.7 (–)	1.5 (–)						··· (–)	n.a.	0.4 (–)	0.2 (96%)							11	
SERVICE	Raw materials handling, etc.														1.6 (–)								
	Generation of heat														0.5 (–)	4.0 (–)							

Abbreviations: n.a. = information not available; ··· = traces.

Table 6:7 shows quite clearly that before July 1, 1969, very few plants were operating any equipment for controlling waterborne residuals. Measures to reduce particulate emissions were undertaken at most point sources except at the electric arc furnaces, the open hearth furnaces, and the adjustment ladles.

6.3 TECHNICAL EFFICIENCY AND COSTS OF EMISSION CONTROL MEASURES UNDERTAKEN BETWEEN JULY 1, 1969 AND JUNE 30, 1973

6.3.1 Coking

Emission control measures undertaken at the only Swedish coking plant in operation consisted of the installation of a scrubber unit (including sedimentation of scrubber water) for treatment of the airborne residuals generated during the charging of the ovens. These ovens were, as pointed out in section 6.2, equipped with suction fans for so-called "direct extraction". This measure accomplished an 89 % reduction of particulate emissions and a 95 % reduction of tar emissions to the atmosphere. The effects of the added measures were to increase the total degree of particulate discharge reduction to 92 % (or more specifically, from 0.4 kg/ton of coke to 0.2 kg/ton) and tar discharge reduction to 98 % (or from 0.3 kg/ton to 0.1 kg/ton). The (gross) annualized costs of these measures amounted to 269.0 thousand S.Cr. (corresponding to approximately S.Cr. 0.39/ton of coke). The government subsidy was 25 % of the investment expenditure thereby reducing the annualized costs by 10 % to 243.5 thousand S.Cr. (or to roughly 0.35/ton of coke).

However, since there was only one observation for the coking process, it is hardly possible to generalize about emission control costs for this part of the production process.

6.3.2 Sintering

The Swedish production of sinter (approximately 7.9 million tons in 1973) takes place in fourteen different plants, six of which are integrated with steel plants. The three plants undertaken measures for additional reduction of particulates emissions accounted for roughly 35 % of total sinter production. The capital expenditures associated with these measures amounted to about 13.7 million S.Cr. Two thirds of this sum were financed by government subsidies. However, since capital costs accounted only for about 20 % of total costs, the reduction of the total annualized costs was only around 22 % or from 11.1 million to 8.7 million S.Cr.

The control measures undertaken by these three plants resulted in a reduction of particulate emissions by roughly 6,500 tons/year or by 19.5 tons/day (assuming a capacity utilization of 85 %). As can be seen from Table 6:8 (which contains a detailed description of the three observations from the sintering operations), the treatment costs per kg of discharge reduction varied between 1.12 and 2.52 S.Cr. A possible interpretation of the data is that an upgrading of the treatment from the 80-85 % efficiency range to the 90 % range will lead to costs around 2.50 S.Cr. per kg, whereas the costs per kg of discharge reduction of installing a complete set of treatment equipment at a previously untreated plant would be around 1.00 S.Cr. Another interesting observation that can be made from Table 6:8 is that only one of the three plants were complying with the EPB emission "guide-lines" of 1.0 kg particulates per ton of sinter. It should be pointed out, however, that the Oxelösund plant in the fall of 1973 completed measures to reduce the diffuse dusting from the sinter plant, thereby reducing the total emissions from the sintering plant to 0.44 kg per ton of sinter. These additional measures increased the treatment cost per ton of sinter to roughly 8.20 S.Cr. The cost per kg of discharge reduction remained almost unchanged, however. It is perhaps also worth noting in this connection that the emission levels given in Table 6:8 refer to normal operating conditions. Thus, in order to account for the risks of malfunctions or breakdowns of the treatment equipment, the actual level of emission (which is generally monitored under "ideal" conditions) will have to be approximately 30 % under the guide-line level in order to ensure compliance on a monthly basis.

6.3.3 Raw iron manufacturing

In 1973, the Swedish production of raw iron was close to 2.5 million tons. Blast furnaces were operated by seven plants (six of which are included in the present study), and sponge-iron furnaces by two plants. Measures for reducing discharges of waterborne residuals from the gas

Table 6:8. Efficiency and cost of reducing particulate emissions from sintering units at Swedish iron and steel plants

Name of plant	Type of process	Production capacity 10^3 tons/year	Type of treatment equipment	Gas-flow $10^3 Nm^3$/hour	Residual	Emissions Before reduction kg/ton	Emissions After reduction kg/ton	Reduction kg/ton	Reduction %	Investment expenditure 10^3 S.Cr	Subsidy %	Total annual. costs 10^3 S.Cr	Annual. costs per ton S.Cr./ton	Annual costs per kg red. S.Cr./kg	Red. in annual. costs due to subsidies %
Luleå	P	760	BF*	140	Part.	1.61**	1.40	0.21	(86.7)	1,425	75	401.8	0.53	2.52	43.4
Domnarvet	P	1,350	MUC	670	Part.	2.16**	0.94	1.22	(89.6)	4,550	50	4,139.1	3.07	2.52	9.1
Oxelösund	SM	900	ESP BF+ ESP	750 347	Part.	7.68	1.20	6.48	84.4	7,700	75	6,539.1	7.27	1.12	28.5
Total		3,010				3.67	1.13	2.54	(87.3)	13,675	66.7	11,080.0	3.68	1.45	21.7

Abbreviations:

P = Pan sintering
SM = Sintering machine

BF = Bagfilter
MUC = Multicyclones
ESP = Electrostatic precipitator

* = Improvement of old unit
** = After previous treatment

cleaning operations were undertaken by three plants (accounting for roughly 75 % of total raw iron production). Half of the capital expenditures of 10.1 million S.Cr. was paid for by government subsidies which reduced the total annualized costs from 3.8 million to 3.0 million S.Cr. (or by approximately 21 %). The range of variation for the gross annualized costs per ton of raw iron was 0.98 to 4.62 S.Cr. The net costs per ton varied between 0.90 and 3.51 S.Cr.

The differences in the unit treatment costs could to a certain extent be explained by the difference in character between the measures undertaken. Thus, in two of the cases the control measures consisted of complete installations of chemical flocculation and sedimentation units, whereas the measure undertaken at the Oxelösund plant consisted of an addition of a chemical flocculation unit only. The costs per ton of raw iron for a complete treatment unit seem to lie in the 3.50 to 5.00 S.Cr. range. An installation of a flocculation unit only would seem to result in treatment costs of around 1.00 S.Cr./ton of raw iron.

By the installation of treatment equipment for the waterborne residuals from the gas cleaning operations at the blast furnaces, the discharges of suspended solids were reduced by approximately 5,200 tons/year (15.6 tons/day). Depending upon the degree of treatment, the treatment costs per kg of SS-discharge reduction vary between 0.50 and 2.00 S.Cr. Table 6:9 contains a detailed description of the efficiency and costs of the emission control measures undertaken at the blast furnaces gas cleaning operations.

6.3.4 Raw steel manufacturing

The number of steel furnaces operated by the plants included in the present study are: 10 basic oxygen furnaces, 13 induction furnaces, 46 electric arc furnaces, and 24 open hearth furnaces. As can be seen from a comparison with Table 6:2, this is a very high degree of coverage except for induction furnaces. This can be explained by the fact that most of the induction furnaces are to be found in the ferro-alloying industry which is not included in the present study.

During the period of government subsidization, 4 basic furnaces, 25 electric arc furnaces, and 10 open hearth furnaces were connected to emission control equipment. Total capital expenditure amounted to 69.8

Table 6:9. Efficiency and costs of measures to reduce discharges from blast furnace gas cleaning units at Swedish iron and steel plants

Name of plant	Type of process	Production capacity 10^3 tons/year	Type of treatment equipment	Water-flow m^3/hour	Residual	Emissions: Before reduction kg/ton	Emissions: After reduction kg/ton	Emissions: Reduction kg/ton	Emissions: Reduction %	Investment expenditure 10^3 S.Cr	Subsidy %	Total annual. costs 10^3 S.Cr	Annual. costs per ton S.Cr/ton	Annual costs per kg red. S.Cr/kg	Red. in annual. costs due to subsidies %
Hofors		160	CFL CED	420	SS H_2S	2.55 0.02	0.25 ...	2.30 0.02	90.2 99.0	2,000	50	739,8	4.62	2.01	24.0
Luleå		600	CFL SED WRC	1,450	SS h_2S	5.05 0.03	0.35 ...	4.70 0.03	93.1 99.0	6,840	50	2,022.6	3.37	0.72	27.6
Oxelösund		1,090	SFL	1,800	SS H_2S	2.36 0.04	0.53 ...	1.83 0.04	77.5 99.0	1,100	50	1,075.0	0.98	0.54	8.2
Total		1,850				3.25	0.45	2.80	86.2	10,140	50	3,837.4	2.07	0.74	21.3

Abbreviations: CFL = Chemical flocculation
SED = Sedimentation
WRC = Water recirculation
... = Traces

million S.Cr. of which roughly 55 % was financed by subsidies. The total annualized costs of emission control measures which amounted to approximately 25.1 million S.Cr. were reduced by around 24 % to 19.0 million S.Cr.

The emission control measures undertaken at the basic oxygen furnaces received government subsidies covering about 37 % of capital expenditures. The annualized costs were lowered by approximately 12 % by the help of these subsidies. Since only two observations were available, it is hardly relevant to talk about a range of variation for the treatment cost per ton - especially in view of the fact that the measure undertaken at the Domnarvet plant consisted of an improvement of the existing bagfilter rather than an installation of a new one. A further complication for a correct identification of the treatment costs associated with basic oxygen furnaces is the fact that the Degerfors plant has an electric arc furnace connected to the same bagfilter that serves the basic oxygen furnace.

The emission control measures undertaken at the basic oxygen furnaces resulted in a reduction of particulate emissions by approximately 5,600 tons/year or by around 16.8 tons/day (assuming 85 % capacity utilization). Neither of the two plants seem to comply with the EPB guide-lines of 0.3 kg/ton, although this conclusion is somewhat uncertain due to the incompleteness of the data. The data for the two plants can be found in Table 6:10.

The emission control measures applied to the electric arc furnaces accounted for about 60 % of the total capital expenditures for emission control purposes at steel furnaces or for roughly 41.8 million S.Cr. Government subsidies financed ca 55 % of these expenditures - reducing the annualized costs by around 25 % (i.e. from 15.4 to 11.8 million S.Cr.). Two types of equipment were used - venturi scrubbers and bagfilters.6) The gross cost per ton of steel for the four plants using venturi scrubbers ranged between 6.87 and 10.94 S.Cr. The range of unit cost variation for the six plants using bagfilters was substantially greater than for the other plants (i.e. 5.93 to 40.67 S.Cr.). The treatment cost per kg of discharge reduction varied between 0.80 and 3.61 S.Cr.

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6) Due to the high energy requirements venturi scrubbers are generally not used for gas flow rates above 40,000 Nm^3/h.

Particulate emissions from the electric arc furnaces were reduced by roughly 6,300 tons/year or by approximately 18.9 tons/day (assuming again 85 % capacity utilization).

Capital expenditures for emission control equipment at open hearth furnaces accounted for around 21.7 million S.Cr. 60 % of which were subsidized by the government. With the help of this high degree of subsidization, the total annualized costs for these measures were reduced from 6.7 to 4.6 million S.Cr. or by roughly 31 %. The range of variation for the unit treatment cost was approximately 7.00 to 16.00 S.Cr.

The reduction of particulate emissions from open hearth furnaces amounted to approximately 4,375 tons/year which corresponds to a daily reduction of about 13.1 tons. The threatment cost per kg of discharge reduction was between 0.59 and 3.00 S.Cr. Four of the five plants included seemed to be able to comply with the EPB guideline of 1.0 kg/ton for existing units.

The total effect of these control measures on particulate emissions from the raw steel manufacturing process was (under the assumption of an 85 % capacity utilization) a reduction by approximately 16,300 tons per year which is equivalent to 48.8 tons per day. Since the control measures undertaken during the period of government subsidization were concentrated to the furnaces with the highest emissions, the median level of emission was lowered from 4.9 to 0.8 kg/ton for electric arc furnaces and from 3.8 to 1.9 kg/ton for open hearth furnaces. A full description of the efficiency and costs of the emission control measures undertaken at Swedish steel furnaces between July 1, 1969 and July 1, 1973, is given in Tables 6:10-6:12.

6.3.5 Casting

As pointed out in section 6.2.3, most of the casting shops were already at the start of the period investigated equipped with cyclones for reduction of particulate emissions. Thus, only two plants made capital expenditures totalling 1.0 million S.Cr. in order to reduce emissions further. Government subsidies financed 17 % of these expenditures which reduced the total annualized costs from 528 to 500 thousand S.Cr. or by 5.4 %.

Table 6:10. Efficiency and costs of measures to reduce particulate emissions from basic oxygen furnaces at Swedish steel plants

Name of plant	Type of process	Production capacity 10^3 tons/year	Type of treatment equipment	Gas flow 10^3 Nm^3/hour	Residual	Emissions: Before reduction kg/ton	Emissions: After reduction kg/ton	Emissions: Reduction kg/ton	Emissions: Reduction %	Investment expenditure 10^3 S.Cr	Subsidy %	Total annual costs 10^3 S.Cr	Annual costs per ton S.Cr/ton	Annual, costs per kg red. S.Cr/kg	Red. in annual costs due to subsidies %
Domnarvet	BOF (3)	1,000	ESP*	192	Part.	0.65**	0.56	0.09	(98.6)	1,325	35.2	321.6	0.32	3.56	21.9
Degerfors	EAF (1) BOF (1)	60 185	BF	400	Part.	27.0	0.40	26.6	98.5	5,050	37.6	2,709.6	14.64	0.55	11.3
Total		1,245				5.83	0.53	5.30	90.9	6,375	37.1	3,031.2	2.43	0.46	12.7

Abbreviations:
BOF = Basic oxygen furnace
EAF = Electric arc furnace
ESP = Electrostatic Precipitator
BF = Bagfilter
* = Improvement of old unit
** After previous treatment

Table 6:11. Efficiency and costs of measures to reduce particulate emissions from Electric Arc Furnaces at Swedish steel plants

Name of plant	Type of process	Production capacity 10^3 tons/year	Type of treatment equipment	Gas flow 10^3 Nm^3/hour	Residual	Emissions				Investment expenditure 10^3 S.Cr	Subsidy %	Total annual costs 10^3 S.Cr	Annual costs per ton S.Cr/ton	Annual costs per kg red. S.Cr/kg	Red. in annual costs due to subsidies %
						RRL Before reduction kg/ton	After reduction kg/ton	Reduction kg/ton	Reduction %						
Björneborg	EAF(1) + A-SKF(1)	90	VS	11.3	Part.	3.6	0.6	3.0	83.3	984	13	328.1	7.29	2.43	6.0
Lesjöfors	EAF(1)	20	BF	21	Part.	20.2	1.2	19.0	94.1	928	50	302.8	15.14	0.80	24.9
Bofors	EAF(3) + HF(2)	71	VS	25	Part.	6.4	0.7	5.7	89.1	2,448	35	744.5	10.49	1.84	18.6
Kilsta	EAF(1)	73	VS	25	Part.	8.0	0.5	7.5	93.7	1,748	50	501.6	6.87	0.92	26.8
Luleå	EAF(3)	125	VS	35	Part.	6.0	2.3	3.7	61.7	3,955	75	1,367.9	10.94	2.96	35.3
Sandviken	EAF(4)	174	BF	88	Part.	6.6	1.6	5.0	75.8	6,500	50	1,852.9	13.52	2.70	26.9
Halmstad	EAF(2)	195	BF	100	Part.	5.7	0.3	5.4	94.7	2,841	50	1,156.3	5.93	1.10	18.2
Domnarvet	EAF(2)	250	BF	150	Part.	7.2	0.8	6.4	88.9	7,200	25	2,950.4	11.80	1.84	9.9
Avesta	EAF(3)	150	BF	500	Part.	7.4	0.8	6.6	89.2	7,000	75	3,457.6	23.80	3.61	25.4
Nyby	EAF(3)	52	BF	750	Part.	16.5	0.44	16.1	97.3	7,000	75	2,114.9	40.67	2.53	40.4
Total	EAF(23) HF(2) A-SKF(1)	1,250				6.84	0.91	5.93	86.7	40,604	55	14,777.0	11.82	1.99	23.7

Abbreviations:
EAF = Electric Arc Furnace
HF = High Frequency Furnace
A-SKF = ASEA-SKF Furnace
VS = Venturi Scrubber
BF = Bagfilter

Table 6:12. Efficiency and cost of measures to reduce particulate emissions from Open Hearth Furnaces of Swedish steel plants

Name of plant	Type of process	Production capacity 10^3 tons/year	Type of treatment equipment	Gas flow 10^3Nm^3/hour	Residual	Emissions				Investment expenditure 10^3SCr	Subsidy %	Total annual. costs 10^3S.Cr	Annual. costs per ton S.Cr/ton	Annual. costs per kg red. S.Cr/kg	Red. in annual. costs due to subsidies %
						Before reduction kg/ton	After reduction kg/ton	Reduction kg/ton	Reduction %						
Sandviken	CHF(1)	18	BF	15	Part.	8.4	0.4	8.0	95.2	700	25	288.3	16.02	2.00	9.9
Smedjebacken	CHF(1) + EAF(1)	95 + 10	ESP	55	Part.	13.1	0.8	12.3	94.2	2,335	50	766.9	7.30	0.59	24.0
Sandviken	OHF(3)	73	ESP	64.1	Part.	8.4	0.4	8.0	95.2	2,640	25	884.8	12.12	1.52	12.1
Hällefors	OHF(3)	177	ESP	92	Part.	5.8	1.1	4.7	81.0	9,000	60	2,499.3	14.12	3.00	35.3
Hofors	OHF(2)	160	ESP	150	Part.	15.6	0.3	15.3	98.1	7,000	75	2,252.9	14.08	0.92	37.9
Total	OHF(10) + EAF(1)	533				10.62	0.97	9.65	90.9	21,675	61	6,692.2	12.56	1.30	30.7

Abbreviations: OHF = Open Hearth Furnace
EAF = Electric Arc Furnace

BF = Bagfilter
ESP = Electrostatic precipitator

The total reduction of particulate emissions from the casting shops amounted to approximately 1,200 tons/year which corresponds to 3.6 tons/day.

6.3.6 Hot forming

During the period of government subsidization of emission control investments, ten steel plants made capital expenditures of 19.4 million S.Cr. in order to reduce the concentration of suspended solids and oil in the water from the scale pits of the forging and rolling mills. These capital expenditures were financed to 55 % by government subsidies and the resulting reduction in annualized costs was close to 25 % or from about 7.0 to 5.3 million S.Cr. The annualized cost per ton of product processed varied between approximately 0.50 and 7.00 S.Cr.

The discharges of suspended solids were reduced by around 5,900 tons/year (or by 17.7 tons/day) and the discharges of oil by approximately 625 tons/year (1.9 tons/day). As a result of these discharge reductions, the median discharges of suspended solids and oil from the hot rolling sections were lowered to 0.5 and 0.1 kg/ton respectively. The efficiency and costs of the various measures to reduce the emissions of waterborne residuals from the hot forming shops are given in Table 6:13.

6.3.7 MANUFACTURING

The waterborne residuals generated in the manufacturing section of the steel plants were generally not subjected to any advanced forms of treatment at the beginning of the period under scrutiny. Since there were strong indications that these discharges could cause severe damage to the environment, large efforts were made to reduce the concentration of residuals in the waste water from this part of the production process. Thus, during the period July 1, 1969 to July 1, 1973 capital expenditures of 33.2 million S.Cr. were made in order to reduce discharges of waterborne residuals from this section. Government subsidies financed roughly 45 % of these expenditures and the total annualized costs of these measures were thereby reduced from 11.1 to 8.6 million S.Cr. (i.e. by approximately 22 %). The wide range of variation of the unit treatment costs

Table 6:13. Efficiency and costs of measures to reduce discharge of waterborne residuals from hot forming shops at Swedish steel plants

Name of plant	Type of process	Production capacity 10^{3}tons/year	Type of treatment equipment	Water flow m^3/hour	Residual	Emissions				Investment expenditure 10^{3}S.Cr	Subsidy %	Total annual. costs 10^{3}S.Cr	Annual. costs per ton S.Cr/ton	Annual. costs per kg red. S.Cr/kg	Red. in annual. costs due to subsidies %
						Before reduction kg/ton	After reduction kg/ton	Reduction kg/	Reduction %						
Vikmanshyttan	HR	10	SED OS	120	SS Oil	4.0 0.24	0.32 0.01	3.68 0.23	92.0 95.8	61	26	53.5	5.35		4.9
Nyby	HR	18	SED OS	120	SS Oil	0.9 3.1	0.1 0.1	0.8 3.0	88.9 96.8	158	25	78.0	4.33		9.2
Boxholm	HR	70	SED OS	190	SS Oil	2.7 0.23	0.34 0.01	2.36 0.22	87.4 95.7	1,300	50	492.8	7.04		21.4
Degerfors	HR	75	SED OS	135	SS Oil	3.3 0.32	1.3 0.1	2.0 0.22	60.6 68.8	450	50	154.2	2.06		25.2
Hällefors	HR	140	SED (HYC)	n.a.	SS	3.2	0.6	2.6	81.3	1,885	75	659.5	4.71		34.8
Bofors (+Kilsta)	HR+ CF	150	OS*	(3,200)	Oil	0.8**	0.5	0.3	(n.a.)	1,125	25	593.5	5.94		7.6
Hofors	HR	645	SED	270	SS	1.8	0.5	1.3	72.2	900	75	308.2	0.48		35.4
Hofors	HR	230	SED	380	SS	3.2	0.5	2.7	84.4	1,300	50	442.0	2.01		16.9
Smedjebacken	HR	655	CFL SED FLT	1,200	SS Oil	2.6 0.12	0.2 0.04	2.4 0.08	92.3 66.7	2,820	75	1,153.2	1.76		30.1
Domnarvet	HR	1,100	SED SOP	2,000	SS Oil	5.6 0.7	2.7 0.2	2.9 0.5	51.8 71.4	9,000	50	2,829.3	2.57		25.7
Total		3,093			SS Oil	3.46 0.34	1.21 0.11	2.25 0.23		18,990.0	55	6,764.2	2.19		25.6

Abbreviations: HR = Hot rolling
CF = Cold finishing
SED = Sedimentation
OS = Oil separation
HYC = Hydrocyclone
CFL = Chemical flocculation
FLT = Flotation
SOP = Separation of pipes
* = Improvement of existing unit
** = After previous treatment

can to a large extent be explained by the great variety of the control measures undertaken.

The great variety is also reflected in the ways in which the physical effects of these measures were reported in the subsidy applications. Consequently, it was impossible to get a clear picture of the resulting discharge reductions.

6.3.8 Summary

Between July 1. 1969 and July 1, 1973 the capital expenditures for emission control purposes in the Swedish iron and steel industry amounted to approximately 178 million S.Cr. Close to 51 % of these expenditures were financed by subsidies thereby reducing the total annualized costs from 74.8 to 58.8 million S.Cr. or by roughly 21 %.7)

The emission control measures undertaken in the iron and steel industry resulted in an average cost increase of an order of magnitude of 13.2 S.Cr. per ton of raw steel. By means of the subsidization, the average cost increase was lowered to 10.4 S.Cr./ton of steel. In comparison with the 1973 average price per ton of steel, the gross cost increase amounted to roughly 1.1 %. A summary of the costs and effects of the emission control measures undertaken at the various subprocesses is given in Table 6:14.

6.4 ANALYSIS OF EMISSION CONTROL COSTS AT THE PLANT LEVEL

As shown in section 2 of this chapter, most of the subprocesses in the iron and steel production process generate more than one residual. In Chapter 3 it was pointed out that in order to fit the decision-makers' purposes, the treatment costs should be expressed in S.Cr per kg of discharge reduction. The disaggregation of the production process into its various components was an attempt to allocate the emission control costs of the individual plants between the different residuals. As could be seen in the preceding section, such a cost allocation could be reasonably well achieved only for particulates. The costs for reducing

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7) It should perhaps be pointed out that the 16.0 million reduction of annualized costs affects gross profits. Under the assumption of an average corporate tax rate of 60 %, the effect on net profits will be only around 6.4 million S.Cr.

Table 6:14. Summary of costs and effects of the emission control measures undertaken by the Swedish iron and steel industry between July 1, 1969 and July 1, 1973. (Figures within brackets are estimated.)

Processing step	Production capacity 1969	Capital expenditures	Subsidy	Cost reduction due to subsidies	Total annualized costs	Cost/ton	Type of residual	Maximum total discharge reduction		Cost/kg reduction
	10^3 tons/year	10^3 S.Cr	%	%	10^3 S.Cr	S.Cr/ton		tons/year	tons/day	S.Cr/kg
Coking	530	630	25.0	9.5	269.0	0.39	Particulates	117.3	0.4	
							Tar	117.3	0.4	
Sintering	3,010	13,675	66.7	21.7	11,080.0	3.68	Particulates	7,645.4	22.9	1.45
Raw iron manufacturing	1,850	10,140	50.1	21.3	3,837.4	2.07	Susp.solids	5,180.0	15.5	(0.74)
							H_2S	64.8	0.2	
Raw steel manufacturing BOF	1,245	6,375	37.1	12.7	3,031.2	2.43	Particulates	6,598.5	19.8	0.46
EAF	1,250	40,604	55.0	23.7	14,777.0	11.82	Particulates	7,412.5	22.2	1.99
OHF	533	21,675	61.0	30.7	6,692.2	12.56	Particulates	5,143.5	15.4	1.30
Casting	89	1,010	17.3	5.4	528.3	5.94	Particulates	1,406.2	4.2	0.38
Hot forming	3,093	18,999	55.0	25.6	6,764.2	2.19	Susp. solids	3,742.5	11.2	(1.81)
							Oil	711.4	2.1	
Manufacturing	1,594	33,206	45.0	22.3	11,083.4	6.95	Metals	(3,330.0)	(10.0	
							Acids	(1,700.0)	(5.1)	
Service, etc.		31,439	42.0	21.1	16,704.8					
Total	~~5,647~~	177,753	50,6	21.4	74,767.5	13.24	Particulates	28,323.4	85.0	
							Susp. solids	8,922.5	26.8	
							Oil	711.4	2.1	

the discharges of suspended solids could be identified only by regarding the simultaneous reductions of hydrogen sulfide and oil as beneficial side-effects with a zero weight (price).

At a first glance, the iron and steel production process might seem analytically quite "simple". First of all, the various sub-processes are easily separable (which is illustrated by the fact that most of the sub-processes can be carried out in separate plants). Secondly, the technical possibilities for discharge reductions in one sub-process are relatively independent of the treatment measures undertaken in other sub-processes. In spite of this "simplicity", the data presented in the preceding section, indicated that some problems of joint cost allocation would remain even at such a disaggregated level of analysis. Some of these problems could probably be eliminated by a further disaggregation of the production (and treatment) processes.

Since such an approach is not possible here, the only remaining alternative if emission control costs are to be expressed in S.Cr. per kg of discharge reduction is for the present author to attach weights to the different residuals. Since such a set of weights would be based on an "uninformed guess" about the marginal damage associated with the different residuals, it will only be done for the residuals from the blast furnaces (i.e. suspended solids and hydrogen sulfide) and from the hot rolling mills (i.e. suspended solids and oil). In both cases suspended solids will be given the weight one (1) and the other residual the weight zero (0). Thus, in Tables 6:15 and 6:16, the annual costs of reducing particulates and suspended solids, respectively, are aggregated to the plant level.

Although these tables contain data on emission control costs expressed in S.Cr. per kg of discharge reduction, the analysis of the tables does not lead to particularly strong conclusions. Suffice it therefore to make some general remarks brought forward by the tables. The first remark concerns the distribution of the total discharge reductions between the plants. As far as suspended solids are concerned, the three biggest plants (accounting for two thirds of total steel production) account for over 80 % of the total discharge reduction but for less than 50 % of the total costs. The reductions of particulate discharges are more evenly distributed and the three biggest plants account for only 42 % of total reductions. The second remark refers to the fact that it has not been possible to find any relationships between the degree of treatment and the treatment cost per kg of discharge reduction. Thus, the economists' notion of an upward sloping treatment cost function is not confirmed by Tables 6:15 and 6:16.

A discussion of the impact of the emission control efforts on the profitability of individual plants could take as its starting point Table 6:17 where the total annualized costs of the emission control measures are distributed between plants. Since it is common practice to assume certain economies of scale in emission control, one would expect such scale economies to show up in this table. As can be seen in the table, the government subsidization resulted in cost reductions varying between 5 and 34 % of total annualized costs. There are no clear indications, however, of any particular pattern in the impact of the subsidies. Neither are there any clear evidence that the smaller (and older?) plants have been more heavily subsidized than the larger, more modern ones and that the subsidies have been "preserving" small (and obsolete?) plants.

Table 6:16. Annual costs of reducing discharges of suspended solids at Swedish iron and steel plants between July 1, 1969 and July 1, 1973

Code	Plant	Type of product	Location	Production capacity (1969)	Production capacity (1975)	Raw residual load	Discharges (1969)	Discharges (1975)	Discharge-reductions		Annual costs		
				10^3 tons/y	10^3 tons/y	kg/ ton	kg/ ton	kg/ ton	kg/ ton	ton/ year	10^3 S.Cr.	S.Cr./ ton	S.Cr./ kg
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	Vikmans-hyttan		I	10	15	6.6	6.6	2.0	4.6	46	53.5	5.35	1.16
	Lesjö-fors		I	20	50	4.5	4.5	0.8	3.7	74	195.7	9.79	2.64
	Björne-borg		I	45	45	6.9	6.9	0.4	6.5	293	n.a.	n.a.	n.a.
	Stor-* fors		I	60*	75*	6.5	6.5	1.0	5.5	330	1,090.4	18.17	330
	Boxholm		I	70	130	3.9	3.9	0.4	3.5	245	492.8	7.04	2.01
	Bofors		I	71	71	2.4	2.4	0.0	2.4	170	1,811.7	25.52	10.63
	Nyby		I	91	120	0.9	0.9	0.1	0.8	73	927.0	10.19	12.73
	Kilsta		I	105	105	9.9	3.0	0.6	2.4	252	364.3	3.47	1.45
	Deger-fors		I	186	260	2.9	2.9	1.9	1.0	186	154.2	0.83	0.83
	Smedje-backen		I	288	355	8.6	5.9	0.3	5.6	1,613	1,251.1	4.34	0.78
	Hofors		I	295	340	8.1	8.1	0.5	7.6	2,242	3,134.8	10.63	1.40
	Hälle-fors		I	310	340	10.3	3.1	1.8	1.3	403	659.5	2.13	1.64
	Luleå		C	900	1,900	19.2	19.2	1.2	18.0	16,200	3,497.1	3.89	0.22
	Oxelö-sund		C	930	1,200	4.1	3.1	0.7	2.4	2,232	1,075.0	1.16	0.48
	Domn-arvet		I	1,300	1,500	6.7	6.7	2.8	4.9	6,370	5,345.6	4.11	0.84
	Total			4,681	6,506	8.7 (40.824)	7.7 (36,159)	1.4 (8,993)	6.6	30,729	20,052.7	4.28	0.65

* Rolling mill

I = inland location
C = coastal location

Table 6:15. Annual costs of reducing particulate emissions of Swedish iron and steel plants between July 1, 1969 and July 1, 1973

Code	Plant	Type of product	Location	Production capacity (1969)	Production capacity (1975)	Raw residual load	Discharges (1969)	Discharges (1975)	Discharge-reductions		Annual costs		
				10^3 tons/y	10^3 tons/y	kg/ton	kg/ton	kg/ton	kg/ton	ton/year	10^3 S. Cr.	S. Cr./ton	S. Cr./kg
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	Vikmanshyttan		I	10	15	15.5	7.2	1.3	5.9	59	68.3	6.83	1.16
	Lesjöfors		I	20	50	20.3	20.3	0.3	20.0	400	302.8	15.04	0.76
	Björneborg		I	45	45	24.2	19.0	1.2	17.8	801	904.2	20.09	1.13
	Söderfors		I	57	90	13.7	2.2	1.4	0.8	47	180.5	3.17	3.96
	Boxholm		I	70	130	4.7	4.7	2.4	2.3	161	49.9	0.71	0.31
	Bofors		I	71	71	34.4	9.6	3.4	6.2	440	744.5	10.49	1.69
	Nyby		I	91	120	48.6	31.2	5.1	26.1	2,375	2 593.3	28.50	1.09
	Kilsta		I	105	105	12.8	11.5	2.5	9.0	945	983.8	9.37	1.04
	Surahammar		I	150	200	25.7	21.7	0.9	20.8	3,120	251.5	1.68	0.08
	Avesta		I	160	195	45.8	22.6	14.0	8.6	1,376	3,457.6	21.61	2.51
	Halmstad		C	180	245	18.2	8.2	1.7	6.5	1,170	1,156.3	6.42	0.99
	Degerfors		I	186	260	43.6	41.7	4.4	37.3	6,938	2,709.6	14.57	0.39
	Sandviken		I	191	320	14.9	12.7	1.3	11.4	2,177	3,680.0	19.27	1.69
	Smedjebacken		I	288	355	8.1	6.0	0.8	7.2	2,074	1,700.3	5.90	0.82
	Hofors		I	295	340	52.7	16.4	6.7	9.7	2,862	2,297.9	7.79	1.16
	Hällefors		I	310	340	9.3	7.6	0.5	7.1	2,201	3,079.1	9.93	1.40
	Fagersta		I	325	525	42.2	3.9	1.9	2.0	650	574.7	1.77	0.89
	Luleå		C	900	1,900	189.4	6.3	1.3	5.0	4,500	2,982.2	3.21	0.64
	Oxelösund		C	930	1,200	92.5	7.2	2.0	5.2	4,836	7,644.8	8.22	1.58
	Domnarvet		I	1,300	1,500	49.4	11.3	2.9	8.4	10,920	8,280.1	6.37	0.76
	Total			5,684	8,006	68.9 (391,567)	11.0 (62,291)	2.5 (19,473)	8.5	48,052	43,551.4	7.66	0.90

I=inland location
C=coastal location

Table 6:17. Total annualized costs of emission control measures undertaken at Swedish iron and steel plants between July 1, 1969 and July 1, 1973

Code	Plant	Type of product	Location	Production capacity	Total capital expenditures	Total subsidies	Total annual costs (gross)		Percent of reduction of annual costs
				10^3 tons/ year	10^3 S.Cr.	10^3 S.Cr.	10^3 S.Cr.	10^3S.Cr./ ton	%
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Vikmanshyttan		I	10	109	40	121.8	12.18	5.3
	Lesjöfors		I	20	1,678	839	512.4	25.62	26.7
	Björneborg		I	45	1,599	489	904.2	20.09	8.8
	Söderfors		I	57	1,826	1,087	758.9	13.31	23.2
	Storfors*		I	60	5,178	2,349	2,079.9	34.67	18.0
	Boxholm		I	70	2,559	1,139	1,140.8	16.30	16.2
	Bofors		I	71	4,958	1,929	2,556.2	36.00	12.3
	Långshyttan*		I	80	1,951	976	579.5	7.24	22.7
	Kallinge		C	80	834	417	686.3	8.58	9.9
	Hallstahammar		I	85	350	175	154.2	1.81	18.5
	Nyby		I	91	12,364	7,855	4,257.7	46.79	30.0
	Höganäs		I	105	1,534	287	422.8	4.03	11.0
	Kilsta		I	105	3,514	1,799	1,354.5	12.90	21.6
	Surahammar		I	150	532	331	505.0	3.37	10.7
	Avesta		I	160	12,591	7,992	5,195.5	32.47	24.0
	Halmstad		C	180	2,600	1,300	1,156.3	6.42	18.3
	Degerfors		I	186	6,380	3,190	3,710.3	19.95	15.1
	Sandviken		I	191	16,240	5,875	5,365.5	28.09	17.3
	Smedjebacken		I	288	6,501	3,954	2,951.4	10.25	21.8
	Hofors		I	295	18,350	9,413	6,102.8	20.69	33.9
	Hällefors		I	310	13,561	7,947	4,244.2	13.69	30.5
	Fagersta		I	325	1,741	706	628.7	1.93	16.9
	Luleå		C	900	19,001	10,513	6,572.7	7.30	25.2
	Oxelösund		C	930	10,370	6,952	8,719.8	9.38	24.4
	Domnarvet		I	1,300	31,432	12,451	14,086.1	10.84	14.2
	Total			6,094	177,753	90,005	74,767.5	12.27	21.4

* Rolling mill

I = inland location
C = coastal location

CHAPTER 7

EMISSION CONTROL IN THE SWEDISH PULP AND PAPER INDUSTRY BETWEEN JULY 1, 1969 AND JUNE 30, 1973

7.1 BASIC FACTS ABOUT THE SWEDISH PULP AND PAPER INDUSTRY

7.1.1 Size and composition of output

The Swedish production of pulp was approximately 7.6 million tons in 1969. The proportion of sulphate pulp (kraft) was roughly 53 % whereas sulphite and mechanical pulp both accounted for about 19 % of total production. In 1973, the share of sulphate pulp had increased to about 59 % whereas the share of sulphite and mechanical pulp had decreased to roughly 11 and 15 % respectively. Actual pulp production and its distribution between the different types of pulp is shown for the years 1969-1973 in Table 7:1.

The Swedish pulp and paper industry is to a large extent exporting its final products. Thus, approximately 75-80 % of total pulp and paper production is destined to foreign markets. Western Europe constitutes the dominating market and buys more than 90 % of Swedish pulp and paper exports. Pulp accounts for roughly 60 % of these exports and among the various types of pulp exported, sulphate pulp is the most important.

7.1.2 Size and geographical distribution of plants

By international standards the Swedish pulp and paper industry consists of relatively small plants. Thus only six plants had a production of over 300,000 tons of pulp per year. The size distribution of the Swedish pulp mills is shown in Table 7:2.

As far as the geographical distribution of the Swedish pulp mills is concerned, it must be seen in a historical perspective. In the beginning of the century, when a large number of new pulp mills were established, the most important factors influencing the choice of location were: (1) proximity to raw materials of desired quality, (2) availability of suitable transport routes for raw materials to the plant and for finished products from the plant, (3) existence of an adequate

Table 7:1. Swedish pulp production 1969-1973

	1969		1970		1971		1972		1973	
	10^3 tons	%	10^3 tons	%	10^3 tons	%	10^3 tons	%	10^3 tons	%
Mechanical	1,435	18.8	1,540	18,9	1,448	18.5	1,201	15.3	1,313	14.7
Sulphite, unbleached	612	8.0	617	7.6	605	7.7	568	7.2	661	7.4
Sulphite bleached	849	11.1	871	10.7	827	10.6	351	4.5	333	3.7
Sulphate, unbleached	1,936	25.4	2,138	26.3	2,037	26.0	2,163	27.5	2,457	27.5
Sulphate, bleached	2,132	28.0	2,317	28.5	2,298	29.3	2,410	30.7	2,836	31.7
Semi-chemical	338	4.4	345	4.2	334	4.3	355	4.5	397	4.5
Dissolving	325	4.3	314	3.8	285	3.6	806	10.3	937	10.5
Total	7,627	100.0	8,142	100.0	7,834	100.0	7,854	100.0	8,934	100.0

Sources: Marknadsöversikt 1971, SCPF, and Statistiska Meddelanden I 1974:36, Statistiska centralbyrån.

Table 7:2. Size distribution of pulp plants (integrated and non-integrated) in Sweden 1973*

Production in 10^3 tons/year	Mechanical and semi-chemical	Sulphate	Sulphite	Total	Saknas
< 25	7 (2)	1 (-)	4 (1)	12 (3)	9
26 - 50	9 (5)	3 (2)	11 (3)	23 (10)	13
51 - 75	4 (2)	4 (3)	7 (2)	15 (7)	8
76 - 100	1 (1)	2 (-)	6 (4)	9 (5)	4
101 - 150	6 (5)	5 (4)	1 (1)	12 (10)	2
151 - 200	-	7 (3)	1 (1)	8 (4)	4
201 - 250	-	2 (2)	2 (1)	4 (3)	1
251 - 300	1 (1)	4 (2)	-	5 (3)	2
> 300	2 (2)	4 (4)	-	6 (6)	
Total				94	46

43
5

* Figures within brackets indicate the number of plants in each size category which are included in the study.

supply of acceptable processing water, and (4) possibility to discharge processing residuals into the water. During that time, these conditions were best met by the river estuaries along the northen coast and in the northen part of lake Vänern. However, the rapid expansion of demand for pulp and paper during the last decades necessitated the use of the raw materials base in the south of Sweden as well. This expansion of production capacity was made possible by (among other things) the development of new means of transportation of raw materials (i.e. by trucks instead of by floating) as well as developments in processing and residuals treatment technology. The location and production capacity of the Swedish pulp mills is shown in Figure 7:1.

7.1.3 Size of total emissions

As pointed out in Chapter 5, the pulp and paper industry is one of the principal sources of industrial residuals discharges in Sweden. It is therefore hardly surprising that the pulp and paper industry alone accounted for over one third of the emission control investments undertaken between July 1, 1969 and July 1, 1973 by plants in existence by July 1, 1969. As can be seen from Table 7:3, the 1973 levels of emission remain quite high in spite of the substantial discharge reductions accomplished during the period under investigation. The purpose of the next two sections of this chapter is to study the cost of these discharge reduction and to find out if there are any general conclusions concerning the costs of emission control that can be drawn from these cost data.

1.300 milj. kr.

1450

235 för de utvalda företagen. utbyggnads och reningseffekt.

Table 7:3.a Annual emissions of BOD_7, suspended solids, particulates and SO_2 from the pulp and paper industry 1969 and 1973

Type of residual	Emissions 1969 10^3 tons/year	Utsläpp företag 69	Emissions 1973 10^3 tons/year	Reduction 1969-1973 10^3 tons/year	
BOD_7	630 000	400	480 000	150	~~144~~
Suspended solids	210		80	130	Σ 8000
Particulates	80 840		560 63	17	
SO_2	225		191	34	

Källa: ~~7622 km~~ ~~8984~~

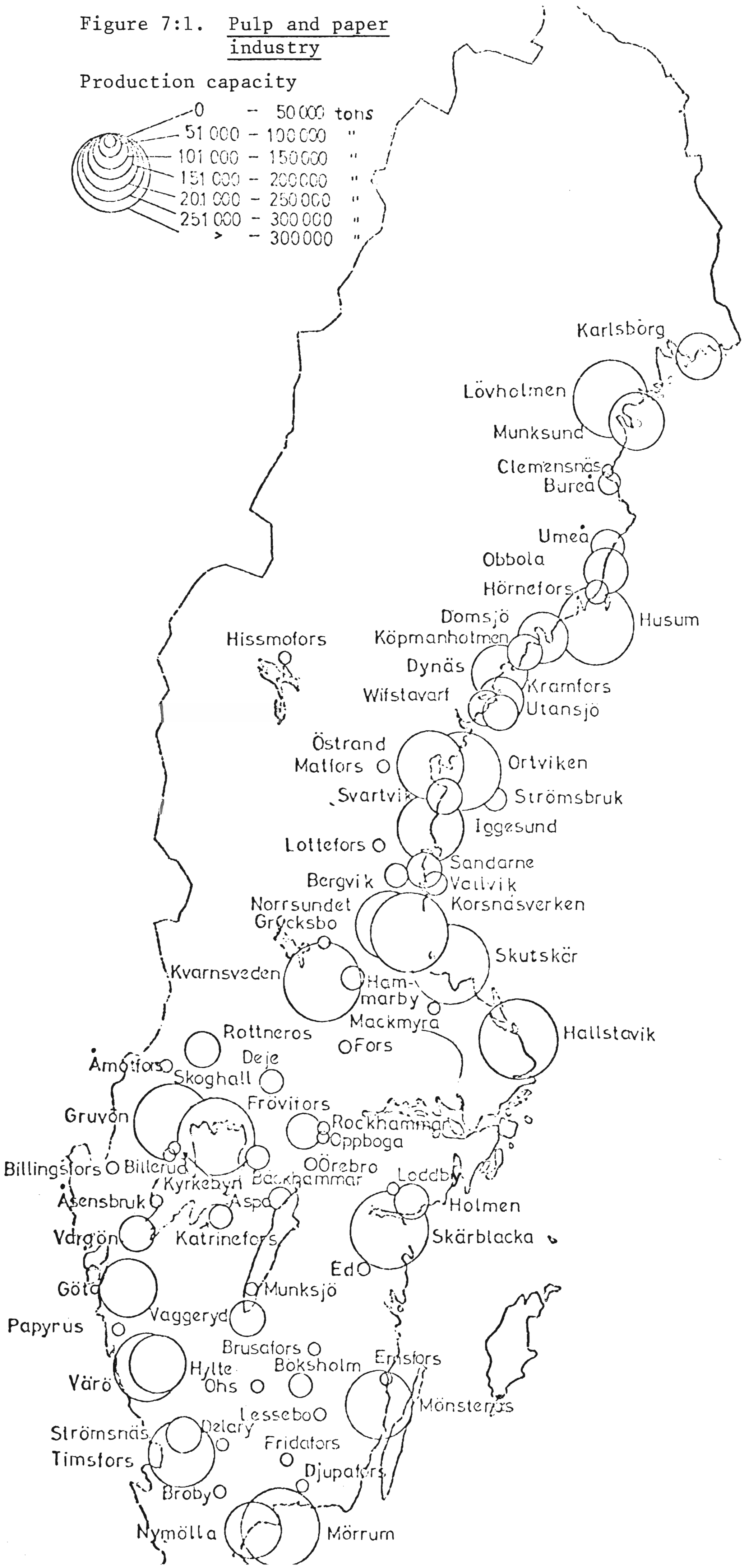
gäller endast för i undersökningen ingående anläggningar.

Jfr sammanställningen av cellulosaind. SNV 1969 [illegible]

inkl. alla anläggningar?

Figure 7:1. Pulp and paper industry

Production capacity



7:2 TECHNICAL CHARACTERISTICS OF PULP AND PAPER PRODUCTION

7.2.1 General description of production processes

The objective of all pulping processes is to separate the fibres in the wood from one another. This separation can be accomplished either by mechanical or by chemical processes.

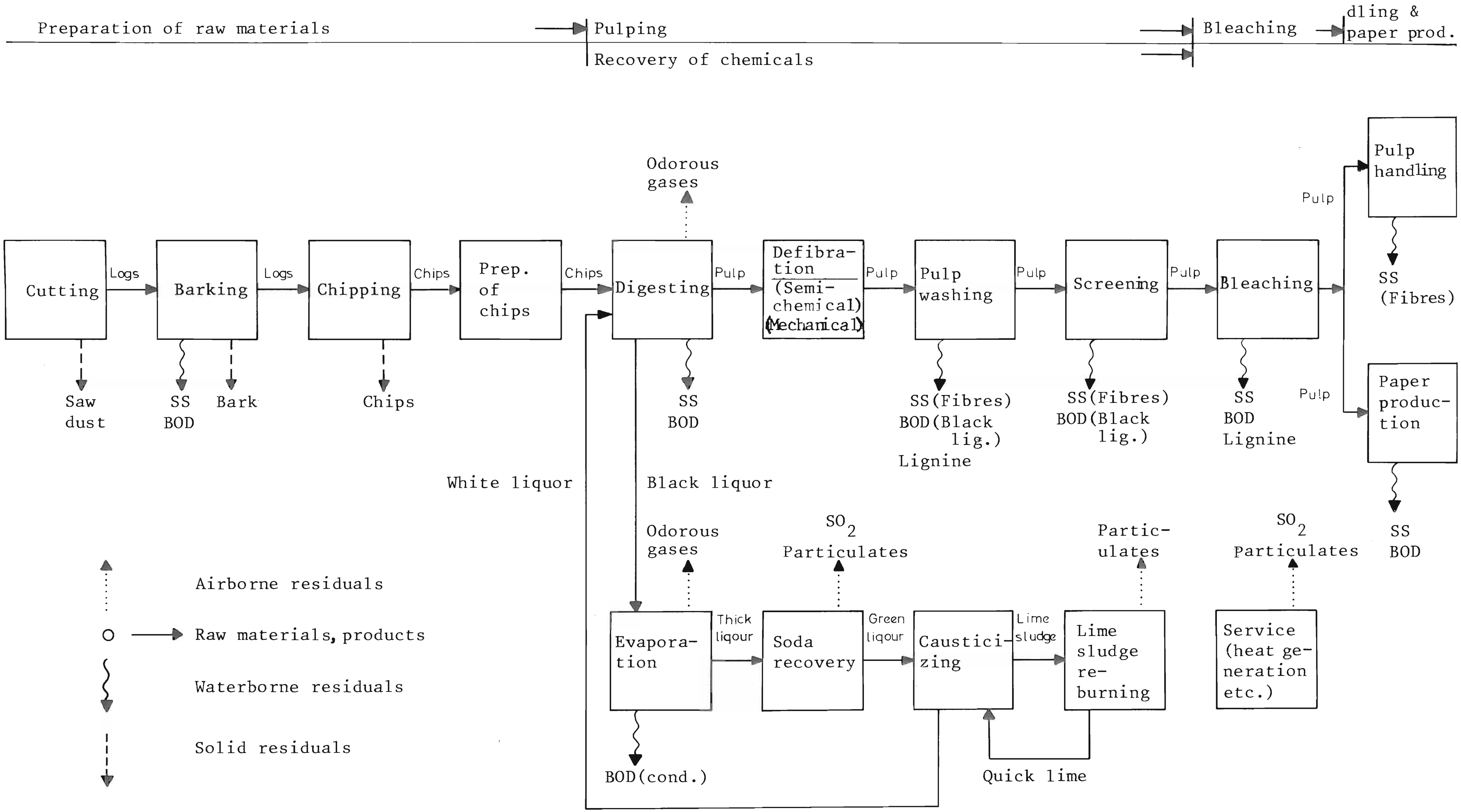
In the mechanical processes, the fibres are separated through the grinding of logs on grindstones in the presence of water. The result of this operation is a slurry consisting of more or less fully separated fibres. By the dewatering of this slurry on a close-meshed metal net, the fibres are matted together into a pulp sheet. Paper made out of such pulp is of limited strength and durability.

In the chemical processes, wood chips are heated with various chemicals in so-called digesters. During this operation, most of the wood's binding agent (i.e. the lignine) is being extracted. This lignine extraction can be accomplished through the use of either an alkaline digesting liquor (primarily consisting of caustic soda) or an acid digesting liquor (either calcium bisulphite or sulphites of magnesium, ammonium, or sodium). The alkaline process, or the sulphate process and the magnesium, sodium, and ammonium processes are characterized by a high degree of recovery and reuse of the chemicals whereas in the calcium-based acid process, no reuse of chemicals takes place.

In addition to these two basic types of production processes, there are a number of processing methods that combine elements of both types of processes. These so-called semi-chemical processes basically contain the same operations as the chemical processes, the difference being that the wood chips are only partially digested and that the pulp therefore needs additional defibration in disk refiners.

The transformation of wood into pulp or paper takes place in a number of distinctly different processing steps. The five principal steps are: (1) Preparation of raw materials, (2) Pulping, (3) Bleaching, (4) Pulp handling and/or paper production, and (5) Recovery of chemicals. These steps, in turn, consist of a number of different sub-processes that are shown in Figure 7:2. Whether all the different sub-processes are actually operated at the individual plants depends on the technology of the plant and on the type of output produced.

Figure 7:2. Principal processing steps in pulp and paper production.



7.2.1.1 Preparation of raw materials

The first step can be divided into four sub-processes, namely (a) crosscutting, (b) barking, (c) chipping, and (d) pretreatment of chips.

In cases where the barking of the logs takes place in short-log barking drums, the logs are cut before the barking rather than after.

For certain types of pulp, some of the elements contained in the bark are undesirable and, therefore, the logs have to be subjected to barking before processing. The bark, constituting between 10 and 15 percent of the weight of the logs, can be separated either by wet or by dry methods.

The next step in the defibration of the wood is the chipping of the logs in chipping machines. Depending upon the quality constraints in the subsequent processing steps, the chips can be either used directly in the digesters or subjected to a number of screening operations.

In some cases the chips are pretreated in water or chemicals in order to facilitate the subsequent defibration in the digester.

7.2.1.2 Pulping

The second processing step can also be divided into four sub-processes, namely (a) digesting, (b) mechanical (or thermomechanical) defibration, (c) pulp washing, and (d) screening.

The purpose of the digesting operation is to have the chemicals react with the lignine in the wood thereby accomplishing the desired separation of fibres. From a chemical point of view it is desirable that the lignine is separated as fast as possible and that the cellulose is affected as little as possible. Simultaneously with the desired separation of fibres there is a certain release of hemi-cellulose during the process. Ideally, the rate of release of hemi-cellulose should be controlled to make sure that the desired pulp quality is achieved.

The digesting generally takes place under high pressure and at high temperature and can be performed either batchwise or continuously. In connection with the production of chemical pulp the mechanical defibration takes place during the "blowing" of the digesters. In the production of semi-chemical pulp, the mechanical defibration generally takes place in disc refiners after the digesters.

Except for some small amounts of spill, the major part of the chemicals used in the digesters are recovered and returned to the process. In the case of production of calcium-based sulphite pulp, there is no technically feasible way of reusing the chemicals and the spent liquor is therefore either burned, spray-dried to lignosulfonic powder, or discharged into the water.

The main objective of the pulp washing is to enable a recovery of processing chemicals by separating the fibres from the released lignine and chemicals. The pulp washing can be performed on filters, in the continuous digester, in diffusers or by so-called radial washing. In the production of sulphate pulp up to 99 percent of the digesting chemicals can be recovered. The corresponding figure for the production of sulphite pulp on a soluble base lies between 95 and 97 percent.

The various screening operations, finally, are undertaken in order to separate the fibres from knots, bark fragments, etc. The screening department generally consists of knot catchers, fine screens, vortex cleaners, reject grinders or equipment of similar types.

7.2.1.3 Bleaching

The fact that many paper qualities require pulp of a high level of brightness necessitates that the pulp is subjected to bleaching with various kinds of chemicals (usually chlorine, sodium hypochlorite, chlorine dioxide, and caustic soda) in a number of steps. The conventional bleaching plant for the production of high brightness sulphate pulp is the C-E-H-(E)-D-E-D sequence, where C designates chlorination, E is for caustic extraction, H is sodium hypochlorite, and D is chlorine dioxide. The most commonly used bleaching sequence used in the sulphite pulp process is C-E-D-E-D. Sometimes other bleaching chemicals are utilized, but the general principles remain the same.

The latest development in bleaching technology is the so-called oxygen bleaching. In this process, which is presently being tried in full scale at a few Swedish pulp mills, the lignine concentration of the pulp is reduced by treating an alkaline pulp sludge (30 % DS) with oxygen under high pressure and at a high temperature. The various operations involved in this process are basically: (a) pressing of the pulp, (b) heating of the pulp, (c) addition of approximately 20 kg of caustic soda per ton of pulp, (d) oxygen treatment, (e) dilution, and (f) washing.

One advantage of the oxygen bleaching process is that the effluent water to a larger extent can be reused in the other processing steps. Furthermore, compared to conventional bleaching, the discharges of BOD_7 and colouring elements are reduced substantially. The major disadvantage with oxygen bleaching is that the pulp loses in strength compared to conventionally bleached pulp.

7.2.1.4 Pulp handling and paper production

In pulp mills that are not integrated with paper mills, the pulp from the bleaching or pulping operations must be dried before shipment. The non-integrated paper mills have operations in which a dry furnish is slurried into a pulp which is then processed to meet the desired product specifications. There are two principal types of machines used for this purpose - the Fourdrinier and the cylinder machine. These machines transform the fibre slurry into a continuous web of paper, which is dried by hot air or by contacting the face of a heated cylinder.

These machines have very high water requirements, most of which can be met by recirculation. Also, these machines have excellent solids retention potential. The recirculation pattern through the machine should provide that all water pulled through the wire before the vacuum boxes be recirculated to the machine headbox. Excess water can be used in the bleaching plant or, in the case of a plant without bleaching unit, in dilution and consistency control of stock after screening. Similarly, a non-integrated paper mill could use excess machine waste water for pulping the dry furnish.

Before drying, the pulp is generally passed through a stock preparation system. This usually consists of screening and centrifugal cleaning to remove dirt and refining to give the desired sheet properties. Both of these operations have good emission control potentials. The effluent stream from the first operation is generally at a consistency of greater than one percent and could not be disposed of at this point. A possible solution would be to pump this effluent water to the knots and shives dewatering station or directly to mill sludge disposal. The refining operation tends to increase the level of fines in the waste water and may restrict the amount of recirculation which can be accomplished.

7.2.1.5 Recovery of chemicals

(a) The sulphate process

The recovery of processing chemicals in a sulphate mill takes place in four principal steps, namely: (a) evaporation of black liquor, (b) incineration of evaporated liquor, (c) causticizing, and (d) lime sludge reburning. In addition to these steps there is generally also some processing of by-products like soap and resin.

The purpose of black liquor evaporation is to evaporate the water in the black liquor so that this liquor can be incinerated and the chemicals recovered. The evaporation takes place in several steps (usually five) where fresh steam is supplied only to the first step and where all the other steps use the vapor from the preceding step. The vapor from the last step of the evaporation unit is lead through surface condensers where the vapor's remaining heat is used for heating water.

Before feeding the black liquor from the pulp washing into the evaporation unit, it is generally mixed with certain amount of thick liquor so that the consistency is increased to roughly 20 %. When the black liquor passes the fifth step its consistency is around 35 %. Final evaporation takes place in steps one and two of the evaporation unit and increases the consistency of the black liquor to approximately 60-65 %.

The condensate generated in the first step is not contaminated with any residual compounds and can therefore be used directly as feed water. The condensates from the other step contain considerable amounts of different alcohols (with a high BOD_7-load) as well as a number of odorous sulphur compounds.

In the production of sulphate (kraft) pulp, the condensates from the digesting step and part of the evaporation condensates can be subjected to external treatment. The major part of the evaporation condensates can be used in the production process and only a small amount of the condensates are discharged into the water.

The incineration of thickened black liquor and the subsequent recovery of alkali takes place in the so-called soda house. The black liquor is incinerated in a special boiler, the soda recovery boiler. The chemicals that are not gasified in the boiler form a smelt which is tapped from the bottom of the boiler and mixed with weak liquor in the soda dissolver. After recuperation of heat, the gases from the soda recovery boiler pass through some kinds of gas cleaning equipment (generally an electrostatic precipitator in combination with a scrubber) where the alkali dust (primarily consisting of sodium sulphate) is recovered.

The next step in the recovery of chemicals involves the transformation of the so-called green liquor in the soda dissolver to white liquor. This is accomplished through a chemical reaction between the green liquor and hydrated lime. This process, which is called caustisizing also forms an insoluble sludge which has to be separated from the white liquor. Thus, the causticizing unit must include equipment for white liquor clarifying and lime sludge washing.

The sludge contains, apart from calcium carbonate (chalk), certain amounts of alkali and un-utilized hydrated lime which is recovered by recausticizing. The calcium carbonate is burned and transformed into de-hydrated lime in a lime sludge reburning kiln.

The weak liquor from the pulp washing contains the resins and the fatty acids of the wood in the form of soap. By collecting the weak liquor in special cisterns, the soap can be separated from the liquor. The soap is then washed and boiled with diluted sulphuric acid. After termination of the boiling, the content of the boiler is allowed to clarify. This leads to the formation of two layers, the upper containing liquid resin and the lower sodium sulphate and un-utilized sulphuric acid. Certain amounts of odorous gases (primarily hydrogen sulphide, H_2S) are generated during this process.

(b) The sulphite process

In the production of sulphite pulp by the calcium-based method there is no reuse of chemicals and the black liquor is either discharged into the water or, if recovered, evaporated, spray-dried and burned.

In the case where a soluble base is used in the production of sulphite pulp some of the processing chemicals are recovered in ways similar to those practiced in the sulphate process. In these cases, the incineration of evaporated black liquor serves the purpose of recovering processing chemicals as well as utilizing the sulphur dioxide.

The most common method of recovering the sulphur dioxide is by absorption in an alkaline scrubber water. Since the concentration of sulphur dioxide in the gases is quite low (i.e. 0.3-1 %), the absorption capacity must be quite large.

In the sodium-based sulphite process, the inorganic compounds of the black liquor form a smelt of sodium sulphide and sodium carbonate. The kind of boiler used is very similar to the soda recovery boiler of the sulphate process. The sulphur dioxide of the exhaust gases is absorbed in a scrubber with alkaline scrubber water.

During the incineration of ammonium-based black liquor, the ammonium hydrate is gasified together with the organic substances of the black liquor. In this case, therefore, only sulphur dioxide can be recovered.

When magnesium-based sulphite pulp is produced, the compounds extracted in the black liquor incineration step are magnesium oxide and sulphur dioxide. The sulphur dioxide of the gases is absorbed in a solution of water and magnesium hydrate.

In connection with the digesting of sulphite pulp, the hemicellulose is hydrolized and transformed into simple saccharic compounds which might then be fermented and distilled into alcohol.

In addition to the various processing steps described above, there is also a number of "service" operations carried out. Among the most important of these services are raw materials handling and transport, preparation of process water, and generation of heat. Most of the necessary heat is generated by incineration of fuel oil. In some plants part of the necessary heat is generated through the incineration of dewatered bark.

7.2.2 Raw residual loads in the Swedish pulp and paper industry

7.2.2.1 Preparation of raw materials

The principal source of residuals in the raw materials preparation stage is the wet barking operation. The amount of residuals generated by this operation varies depending upon the type of wood used and the way in which the logs were transported and stored before barking. Approximately 20 % of the bark's dry weight consists of compounds easily soluble in water. This means that the discharges of degradable organic compounds will be quite large when the barking is performed by the wet method. Thus, the amount of BOD_7 generated by conventional wet barking amounts to between 2 and 14 kg per ton of pulp. The large amount of bark (115-235 kg/ton) resulting from the barking process is either incinerated to produce heat or dumped. In both cases it is necessary to reduce the water content of the bark and bark dewatering is therefore considered part of the process. The waste water from the dewatering operations contains substantial amounts of suspended solids (5-30 kg/ton of pulp) and smaller amounts of BOD_7 (1-4 kg/ton).

The bark separated by the dry barking method has a 40 % dry content and can therefore be incinerated without prior dewatering. Small amounts of water can be used for spraying of the logs before and after barking. This water will contain certain amounts of suspended solids (0-5 kg/ton) and BOD_7 (0-3 kg/ton). The total amount of bark generated by the dry barking process varies between 130 and 250 kg per ton of pulp.

In the crosscutting section, finally, certain amounts of solid residuals are generated. Depending upon the size of the saw blades, the volume of saw dust generated amounts to between 0.5 and 1.0 % of the volume of the logs. Some plants use this residual as an input to the pulping process.

7.2.2.2 Pulping

The waterborne residuals generated during the digesting and washing operations consist primarily of condensates with a high BOD_7-load, suspended solids (fibres), and colouring substances. The raw residual loads are substantially higher in the sulphite process than in the sulphate process and depending upon the large number of alternative techniques available for sulphite pulp production, the range of variation from BOD_7-discharges ranges from 10 to 80 kg per ton of pulp. The range of variation for the raw loads of suspended solids is 10 to 30 kg/ton in the sulphite industry and approximately 8 to 15 kg/ton in the sulphate industry. As far as colouring substances are concerned, the sulphate process generates between 10 and 50 kg/ton.

The airborne residuals associated with sulphate pulp digesting consist primarily of odorous sulphur compounds, less than 50 % of which are condensable. The range of variation for the raw load of these compounds is 1.0 to 4.0 kg/ton for batch digesters and 0.5 to 1.5 kg/ton for continuous digesters. The major airborne residual generated by the digesting operation in the sulphite process is sulphur dioxide. The raw residual load ranges between 2.0 and 20.0 kg/ton.

7.2.2.3 Bleaching

The purpose of the bleaching process is, as pointed out in section 7.2.1, to reduce the concentration of colouring substances in the pulp. These substances consist of lignine, resin, knots, etc. The volume of waste water from bleaching units varies from around 90 m^3/ton in the sulphate process to approximately 150 m^3/ton in the sulphite process. The concentration of residuals in the waste water depends upon a number of factors, the most important of which are:

(1) the concentration of lignine in the unbleached pulp,

(2) the extent to which the pulp has been washed,

(3) the actual bleaching conditions (e.g. chemicals used, temperature, bleaching sequences, desired whiteness of the pulp, etc.).

The raw residual loads from conventional bleaching units at sulphate pulp mills vary between 12 and 18 kg/ton for BOD_7, between 1 and 5 kg/ton for suspended solids, between 40 and 50 kg/ton for lignine, and between 145 and 170 kg/ton of colouring substances. In the few cases where oxygen bleaching has been used, reports indicate a 35-50 % reduction of BOD_7-discharges and a 50-70 % reduction of the discharges of colouring substances.

In the sulphite pulp process, the corresponding raw residual loads from conventional bleaching units are 15 to 60 kg/ton as far as BOD_7 is concerned, 3 to 5 kg/ton of suspended solids, 10 to 40 kg/ton of lignine, and 65 to 70 kg/ton of colouring substances.

At chlor-alkali bleaching units, the ventilation air might contain small amounts of chlorine gases. Under normal operating conditions, however, these emissions should not constitute a problem.

7.2.2.4 Pulp handling and paper production

The pulp handling operations at non-integrated pulp mills generate quite moderate amounts of residuals. For example, the BOD_7-load varies from 0 to 5 kg/ton of pulp whereas the amounts of colouring substances generally vary between 0 and 3 kg/ton of pulp.

Paper production normally generates substantial amounts of waste water contaminated with certain residuals. These residuals consist primarily of suspended solids (i.e. fibres and various paper additives) and dissolved organic substances. These residuals discharges can be reduced either by closure of the paper mill water system or by external treatment.

Measures to increase the degree of water system closure will, however, also increase the risk of operating breakdowns and/or deterioration of product quality. These problems have their origin in the increasing concentration of suspended and colloidal substances in the barkwater and can be solved in two principally different ways. The first method is to reduce the concentration of suspended substances in the pulp slurry by improved washing of the pulp. The second method is to add various chemicals in order to improve the chemical properties of the paper mill backwater. Thus, at an integrated pulp and paper mill, the concentration of suspended substances in the paper mill backwater depends to a large extent on the conditions in the washing section of the pulp mill and emission control measures undertaken in the washing/screening section will have a direct bearing upon the operating conditions in the paper mill.

Depending upon the extent to which internal control measures of the above mentioned kind have been undertaken, the raw residual loads from the paper mill vary between 2 and 5 kg/ton of paper for BOD_7 and between 8 and 35 kg/ton for suspended substances.

7.2.2.5 Recovery of chemicals

As pointed out in section 7.2.1.5, the recovery of chemicals in the sulphate pulp process takes place in four steps. The residuals generated at the first of these, i.e. the evaporation step, consist primarily of condensates with a high BOD_7-load (2-14 kg/ton of pulp), suspended substances (2-6 kg/ton), and odorous sulphur compounds (0.3-1.0 kg/ton).

During the second step of the recovery process, which consists of incineration of the evaporated black liquor, substantial amounts of aireborne residuals are generated. Thus, the raw load of particulates varies between 35 and 90 kg per ton of pulp and the SO_2-load between

4 and 12 kg/ton. In addition to these residuals, small amounts of odorous sulphur compounds (primarily H_2S) can sometimes be found in the exhaust gases of the soda recovery boiler.

The type of residuals generated at the third and fourth steps of the recovery process (i.e. the causticizing and the lime-sludge reburning operations) are primarily particulates (80-90 kg/ton of pulp) and SO_2 (1-3 kg/ton).

In those cases where the gases and condensates generated at the mill are subjected to treatment, the BOD_7-load stemming from condensates can be reduced by approximately 75 %. The retained condensates are either reused in the process or transformed into airborne residuals. The treatment method applied to the odorous gases generated at the digesting and evaporation units, generally consists of incineration.

At calcium-based sulphite pulp plants the digesting chemicals are generally not recovered and the spent liquor is either discharged together with plant waste water (thereby contributing to the total BOD_7-load with between 200 and 420 kg/ton of pulp) or evaporated and burned (thus generating between 100 and 130 kg particulates and 70-80 kg of SO_2 per ton of pulp).

The incineration of spent liquor at sulphite mills using a soluble base is generally combined with a recovery of particulates (since they contain valuable chemicals) and SO_2. This means that the exhaust gases generally are subjected to treatment in cyclones or electrostatic precipitator and alkaline scrubbers. The particulate emissions are thereby reduced to less than 1 kg/ton of pulp and the SO_2 emissions to between 10 and 30 kg/ton of pulp.

7.2.2.6 Summary

As pointed out in the preceding sections, the types and amounts of residuals generated at the various steps of the production processes depend upon a number of different factors. Among the most important of these factors are (1) the quality of the raw materials, (2) the type of processing technology, and (3) the desired quality of the final product(s). The ranges of variation for the raw residual loads from the different processes are therefore often quite substantial. All information available on raw residual loads at Swedish pulp and paper mills is summarized in Tables 7:4a-c.

Table 7:4a. Range of variation of raw residual loads at Swedish sulphate mills

(Figures in brackets are median values)

Sub-process	Processing technology	Waterborne residuals													Airborne residuals					Solids			
		BOD_7	Susp. solids	Lignine	Colour	Acids	Oil	Amm. (NH_3)	Phenols	Sulfides	Cyanide	Chlor (Cl^-)	Sulfates	Zink	Particl.	SO_2	Hydrocarbons	Sulfur comp.	Other	Slag	Sludge	Solids	
Prep. of raw materials (barking, chipping, defibr. etc)	Wet barking*	3 – 18 (5.0)	5–30 (10.0)																			115-235 (160)	Bark dewatering part of process
	Dry barking	0 – 3 (2.0)	0–5 (3.5)																			130-250 (175)	
Digesting	Batch	10–15 (12.0)								< 0.5 (0.2)								1– 4 (2.0)					
	Continuous	8-12 (10.0)								< 0.5 (0.2)								0.5-1.5 (1.0)					
Washing (incl. schreening)	Diffusers	5 – 50 (9.0)	8-15 (12.0)	1 – 10 (5.0)	10 –50 (30.0)													n.a.					
	Filters	3 -10 (6.0)	8-15 (12.0)	1 – 10 (5.0)	10 –50 (30.0)													n.a.					
Bleaching	Chlor-alkali (C-E-~~H~~-(E)--D-F-D)	12-18 (16.0)	1– 5 (3.0)	40-50 (45.0)	145-170 (155.0)																		
	Oxygen	5 – 9 (7.0)	1 – 5 (3.0)	40-50 (45.0)	50-85 (60.0)																		
Pulp handling		0 – 2 (1.0)	1– 3 (2.0)		0 –2 (1.0)																		
Paper production		2– 5 (10.0)	8–35* (30.0)																				*Depending upon the degree of water system closure
Evaporation		2–14 (6.0)	2– 6 (3.5)							0.1-1.8 (0.3)								0.3-1.0 (0.4)					
Treatm. of gases and condensates																2– 6 (4.0)		1.0-3.5 (1.7)					
Soda recovery															35-90 (55.0)	4 – 12 (7.0)		...					
Recov. of chem Caust., lime reburning)															80-90 (85.0)	1 – 3 (2.0)		< 0.4 (n.a.)					
Service (bark. incin., etc.)															3-10 (5.0)	5-15 (8.0)							

n.a. = information not available. ... = traces.

Table 7:4b. Range of variation of raw residual loads at Swedish sulphite pulp mills

(Figures in brackets are median values)

Sub-process	Processing technology	Waterborne residuals													Airborne residuals					Solids			
		BOD$_7$	Susp solids	Lignine	Colour	Acids	Oil	Amm. (NH$_3$)	Phenols	Sulfides	Cyanide	Chlor (Cl$^-$)	Sulfates	Zink	Particl.	SO$_2$	Hydrocarbons	Sulfur comp.	Other	Slag	Sludge	Solids	
Prep. of raw materials (Barking, chipping, defibr., etc)	Wet barking*	3-18 (5.0)	5-30 (10.0)																			115-235 (160.0)	*Bark dewatering part of process
	Dry barking	0-3 (2.0)	0-5 (3.5)																			130-250 (175.0)	
Digesting	Batch	20-60* (30.0)														2-20 (4.0)							*Without liquor incineration (ca): 200-420 kg/ton
	Continous	n.a.														n.a.							
Washing (incl. screening)	Diffusers	20-80 (40.0)	10-30 (20.0)	n.a.																			
	Filters	15-60 (35.0)	10-30 (20.0)	n.a.																			
Bleaching	Chlor-alkali (C-E-D-E-D)	15-60 (30.0)	3-5 (4.0)	10-40 (30.0)	65-70 (68.0)																		
	Oxygen	n.a.	n.a.	n.a.	n.a.																		
Pulp handling		0-2 (1.0)	0-2 (1.0)		0-1 (1.0)																		
Paper production		2-5 (10.0)	8-35* (30.0)																				*Depending upon the degree of water syst. closure
Evaporation		25-35 (29.0)	5-40* (34.0)										15-25 (20.0)			n.a.							*Including washing of evaporation unit
Treatment of gases and condensates		6-8 (7.0)																					
Soda recovery*	Calc. basis														100-130 (115.0)	70-80 (75.0)					n.a.		*Incineration of spent liquor & prop. of new liquor
	Soluble basis											n.a.	n.a.		< 1 (0.8)	10-30 (20.0)					n.a.		
Recov. of chem. (Caust., lime reburning)																							
Service (bark incin., etc.)															3-10 (5.0)	5-15 (8.0)							

n.a. = information not available.

Table 7:4c. Range of variation of raw residual loads of Swedish mechanical/semi-chemical pulp mills. (Figures in brackets are median values)

Sub-process	Processing technology	Waterborne residuals													Airborne residuals					Solids			
		BOD_7	Susp solids	Lignine	Colour	Acids	Oil	Amm. (NH_3)	Phenols	Sulfides	Cyanide	Chlor (Cl^-)	Sulfates	Zink	Particl.	SO_2	Hydrocarbons	Sulfur comp.	Other	Slag	Sludge	Solids	
Prep. of raw materials (barking, chipping, defibr. etc.)	Wet barking*	3 – 18 (5.0)	5 – 30 (10.0)																			115-235 (160.0)	* Bark dewatering part of process
	Dry barking	0 – 3 (2.0)	0 – 5																			130-250 (175.0)	
Digesting	Batch*	10–30 (20.0)														0–3 (1.5)							* Semi-chemical
	Continuous																						
Washing (incl. screening)	Diffusers*	10–30 (20.0)	10–30 (15.0)	2–10 (7.0)																			* Semi-chemical
	Filters*	1 – 20 (15.0)	10–30 (15.0)																				* Groundwood
Bleaching	Chlor-alkali	5 - 15 (10.0)	0 – 5 (2.0)	n.a.	n.a.																		
	Peroxide	15–18 (16.0)																					
Pulp handling		0 – 2 (1.0)	1 – 3 (2.0)		0—2 (1.0)																		
Paper prod.		2 – 5 (10.0)	8 – 35* (30.0)																				* Depending upon the degree of water system closure.
Evaporation																							
Treatm. of gases and condensates																							
Soda recovery																							
Recov. of chem. Caust., lime reburning																							
Service (bark incin., etc.															3–10 (5.0)	5–15 (8.0)							

n.a. = information not available.

7.2.3 Base level of emission control in the Swedish pulp and paper industry

In the pulp and paper industry, the problems associated with the generation of processing residuals were recognized at an early stage and certain emission control measures were in use long before the Environment Protection Act came into force on July 1, 1969. Before this date, the discharges of waterborne residuals were regulated by the Water Laws whereas no special legislation existed as far as the discharges of airborne residuals were concerned.

In order to get at least a rough idea of the effects on discharges of the environmental policy pursued between July 1, 1969 and July 1, 1973 it is necessary to try to specify the level of emission control at the beginning and at the end of this period.

The emission control measures of the "add-on" type that were installed at the beginning of the period consisted primarily of equipment for collection of particulates from the soda recovery boiler (alt. black liquor incinerator) and the bark incinerator and of sedimentation of fibre carrying waste water. Depending upon the type of equipment used, the particulate emissions from these sources are reduced by 90-95 %. Since approximately half of the soda recovery boilers was equipped with some kind of scrubbers (with efficiencies around 80 % for SO_2-reduction), the total SO_2-discharge from this processing step were roughly 40 % lower than the raw load.

At the beginning of the period of investigation, approximately half of all pulp and paper mills were equipped with sedimentation basins for fibre carrying waste water. At the end of the investigated period 80 % of the mills were equipped with such basins. The efficiency of these basins with regard to reductions of the discharges of suspended solids (fibres) varied between 75 and 90 %.

It must be emphasized again, however, that many emission control measures in the pulp and paper industry take the form of process changes rather than an installation of "add-on" residuals treatment equipment. It must also be pointed out that, in some cases, subsidies were given to plants for improvements of existing treatment equipment.

7.3 TECHNICAL EFFICIENCY AND COSTS OF EMISSION CONTROL MEASURES UNDERTAKEN BETWEEN JULY 1, 1969 AND JUNE 30, 1973

7.3.1 Preparation of raw materials

The emission control measures undertaken at this step of the production process were concentrated to the barking operations. In two cases the measures consisted of a change of barking method (i.e. from wet to dry barking), in six cases of improvements of the bark dewatering operations, in one case of sedimentation of the water from the bark dewatering, in one case of water system closure, and in one case of installation of bark storage facilities.

Under the assumption of an average capacity utilization of 85 %, the total reduction of discharges of suspended solids was approximately 8,900 tons/year (or 26.7 tons/day). The total annualized costs for these measures amounted to roughly 1.46 million S.Cr. The government subsidization reduced this cost to 665 thousand S.Cr. or by 45 %. The corresponding unit treatment cost (i.e. the cost per ton of pulp) was 0.76 S.Cr. A detailed presentation of the effects and the costs of the bark dewatering measures is found in Table 7:5.

7.3.2 Pulping

The emission control measures undertaken in this part of the production process were heavily concentrated to the pulp washing operations. The three major measures undertaken were: (a) improvements of the washing in diffusers, (b) installation of equipment for filter washing, and (c) installation of washing presses. These three measures accounted for about 75 % of the capital expenditures on emission control in the pulping step. Through the government subsidies, the total annualized costs were reduced by roughly 28 % or from 10.1 to 7.3 million S.Cr.

Due to the incompleteness of the data it is not possible to make a more detailed analysis of the effects of the different measures. The scattered data seem to suggest, however, that the costs per kg of BOD_7-reduction in the washing section rarely exceed 2.00 S.Cr. and that a common range is 0.20 to 0.60 S.Cr. The treatment costs per ton of pulp seem to lie in the range of 2.00 to 9.00 S.Cr. with a certain concentration in the upper part of this interval. Part of the differences between plants as far as unit treatment costs are concerned could probably

Table 7:5. Efficiency and cost of bark dewatering units in the raw materials preparation stage at Swedish paper mills

Name of plant	Type of process	Production capacity	Type of treatment equipment	Flow	Residual	Emissions				Investment expenditure	Subsidy	Total annual. cost	Annual. cost per ton	Annual. cost /kg red.	Red. in annual. costs due to sub.
						Before	After	Reduction	%						
		10^3 tons/ /year				kg/ton	kg/ton	kg/ton		10^3SCr	%	10^3SCr	SCr/ /ton	SCr/ /kg	%
Broby	SI	50	DW*		SS	5.3	0.5	4.8	90.6	38.4	25	10.7	0.21	(0.04)	14.3
					BOD	n.a.	n.a.	n.a.	n.a.						
Bure	GRB	65	DW*		SS	9.7	3.8	5.9	60.5	200	50	52.7	0.81	(0.14)	30.9
					BOD	n.a.	n.a.	n.a.	n.a.						
Korsnäs	SAB	150	DW*		SS	10.0	3.3	6.7	67.0	500	50	139.9	0.93	(0.14)	28.6
					BOD	n.a.	n.a.	n.a.	n.a.						
Domsjö	SIB	225	DW*		SS	11.9	5.9	6.0	50.4	350	75	159.0	0.71	(0.12)	53.5
					BOD	8.2	6.0	2.2	26.8						
Dynäs	SA	245	DW		SS	16.5	3.3	13.2	80.0	342.5	75	95.8	0.39	(0.03)	43.6
					BOD	n.a.	n.a.	n.a.	n.a.						
Husum	SAB	495	DW*		SS	3.2	0.9	2.3	71.9	265	50	74.1	0.15	(0.07)	26.7
					BOD	n.a.	n.a.	n.a.	n.a.						
Total		1,230				8.7	2.7	6.0	69.0	1,695.9	58.5	532.2	0.43	(0.07)	38.7

be explained by the large differences in the degree of complexity of the different measures. In fact, they range between small improvements of existing equipment to the installation of complete washing units (including in some cases necessary capacity increases in the evaporation unit and in the soda recovery boiler).

7.3.3 Bleaching

Measures to reduce residuals discharges from the bleaching operations were undertaken only by six plants. Since there were five different types of measures undertaken, it is very difficult to draw any general conclusions about the efficiency and costs of controlling discharges from this processing step. However, the total capital expenditures for emission control in the bleaching step amounted to 14.8 million S.Cr. Since approximately 51 % of these expenditures were paid for by government subsidies, the total annualized costs were lowered from roughly 5.5 to 4.2 million S.Cr. or by close to 23 %. The wide range of variation for the unit treatment costs is hardly surprising in view of the great differences in the character of the measures.

Under the assumption of an 85 % capacity utilization, the total reduction of BOD_7-discharges amounted to approximately 5,000 tons/year (15.0 tons/day). The treatment costs per kg of discharge reduction varied between 0.25 and 1.92 S.Cr. and were in four cases out of six under 1.00 S.Cr. In addition to the reduction of the BOD_7-discharges there was also a 5,200 tons/year (15.4 tons/day) reduction in the discharges of suspended solids. The efficiency and costs of measures to reduce discharges of waterborne residuals from bleaching units at Swedish pulp mills are shown in Table 7:6.

7.3.4 Recovery of chemicals

Measures to reduce residuals discharges from the chemicals recovery section were undertaken by no less than 30 plants, 11 of which were producers of sulphite pulp. The capital expenditures for emission control in this section amounted to roughly 146.3 million S.Cr. Government subsidies amounted to approximately 45 % (or 65.2 million S.Cr.) of these expenditures. Approximately 48 million S.Cr. were spent on improvements of <u>existing</u> evaporation and soda recovery units, 51 millio

Table 7:6. Efficiency and costs of measures to reduce discharges of waterborne residuals from the bleaching operations at Swedish pulp mills

Name of plant	Type of process	Production capacity	Type of treatment equipment	Flow	Residual	Emissions				Investment expenditure	Subsidy	Total annual. cost	Annual. cost per ton	Annual cost/kg red.	Red. in annual. costs due to sub.
						Before	After	Reduction	%						
		10^3 tons/ /y				kg/ton	kg/ton	kg/ton		10^3 SCr	%	10^3 S.Cr	SCr/ ton	S.Cr/ kg	%
Lessebo	SIB	30	CDO[a]		SS	5.5	3.2	2.3	41.8	620	75	283.9	9.46	0.78	26.6
					BOD	19.4	7.3	12.1	62.4						
Billingsfors	SAB	45	OBL		SS	9.4	2.3	7.1	75.5*	1,700	25	213.8	4.75	0.25	32.4
					BOD	24.9	6.2	18.7	75.1*						
Hallstavik	GR SIB	60 (420)	BL[a]		SS	9.3	8.8	0.5	5.4						
					BOD	25.3	2.8	22.5	88.9	(1,370)	15	588.9	9.82	0.43	5.7
Strömsbruk	SIB	90	WSC		SS	73.4	10.8	62.6	85.3*			787,3	8.75	0.60	55.8
					BOD	21.6	6.9	14.7	68.1*	(3,600)*	75				
Gruvön	SAB SIB	157 (640)	OBL		SS	n.a.	n.a.	n.a.	n.a.	5,353	40	1,600,0	10.19	1.92	21.8
					BOD	13.4	8.1	5.3	40.0						
Skoghall	SAB SIB	325	IEX		Cl^-	5.9	4.8	1.1	18.6	2,200	75	1,982.9	6.10	1.69	13.4
					BOD	4.8	1.2	3.6	75.0						
Total		707			BOD	12.5	4.2	8.3	66.4	14,843	51	5,456.8	7.72	0.93	22.6

* = Including measures in the screening dept.

a = Improvements of existing units

( ) = Reduced by the EPB

S.Cr. on new chemical recovery units, 15 millions on treatment of gases and condensates from the digesting and evaporation units, and 14.5 millions on treatment of gases from soda recovery boilers. The remaining 19 millions were spent on a variety of different emission control measures among which stripping columns (accounting for approximately 4 millions) were the most important.

The total annualized costs of these measures amounted to roughly 40.8 million S.Cr. The government subsidies resulted in a reduction of this cost by almost 10.6 millions or by 26 %.

The total discharge reductions accomplished by these control measures were difficult to determine due to the incompleteness of the data. However, the BOD_7-discharges were reduced by at least 27,350 tons/year (82.0 tons/day), the SS-discharges by at least 8,650 tons/year (26.0 tons/day), the particulate emissions by at least 3,700 tons/year (11.1 tons/day), the SO_2-emissions by at least 18,350 tons/year (55.1 tons/day), and the H_2S-emissions by at least 1,865 tons/year (5.6 tons/day).

The enormous variations in the costs of improvements of the chemicals recovery in sulphite pulp mills can to a large extent be explained by the differences in the degree of complexity of the measures since these range from improvements of existing evaporation units to the construction of complete chemical recovery units. The average unit cost for the 8 plants concerned was approximately 50.00 S.Cr. whereas the median unit cost was around 37.00 S.Cr.

The unit costs associated with improvements of the evaporation units at sulphate pulp mills displayed a somewhat smaller range of variation (i.e. 1.27 to 6.70 S.Cr.), and the average cost for the four included plants was as low as 2.96 S.Cr. per ton of pulp.

Three of the four plants undertaken measures for treatment of odorous gases and condensates experienced unit treatment costs in the range of 6.00 to 8.50 S.Cr. The average cost for the four plants was 6.31 S.Cr.

The range of variation for the unit treatment costs associated with treatment of the gases from the soda recovery boiler was quite large, but there seemed to be a certain concentration in the 4.00 to 6.00 S.Cr. interval. The average cost for the six plants was 4.73 S.Cr.

The wide range of variation for the unit costs of stripping column finally, can partly be explained by the differences in the complexity of the installations. Thus, the average unit cost of 2.61 S.Cr. might not be very representative for this type of operation and it might be more realistic to expect a unit cost in the 3.00 to 6.00 S.Cr. range. The distribution of the emission control costs between the various processes within the chemicals recovery section is shown in Table 7:7.

7.3.5 Service operations

One of the most important services operations at a pulp mill is the generation of heat. In most plants heat is generated by burning fuel oil in large boilers. In order to improve its energy balance and reduce a solid waste disposal problem, some plants incinerate the dewatered bark together with fuel oil in special boilers. Since the incineration of bark generates large amounts of particulates, it has become common practice to combine the bark incinerators with some kind of treatment equipment. During the period under investigation, 14 plants were given government subsidies to install adequate gas cleaning equipment on their bark incinerators. The most commonly used type of equipment were cyclones. The range of variation for the unit costs associated with this type of equipment was quite small (i.e. between 0.30 and 2.40 S.Cr. if the high costs of the electrostatic precipitator is excluded). The capital expenditures for emission control equipment in connection with bark incinerators were close to 16.3 million S.Cr., 38 % of which were financed by government subsidies. Through these subsidies the total annualized costs were reduced from 4.1 to 2.9 million S.Cr., or by almost 30 %. The particulate emissions were reduced by at least 8,100 tons/year (24.3 tons/day).

The two most commonly used methods for reduction of discharges of waterborne residuals from the various operations are (a) water system closure, and (b) final sedimentation (often with chemical flocculation added). Between July 1, 1969 and July 1, 1973 the plants under investigation made capital expenditures of over 118.2 million S.Cr. 50 % of which were subsidized. By the subsidies, the annualized costs were reduced from 28.9 to 21.9 million S.Cr., which corresponds to a reduction by roughly 24 %. The large variation in unit costs can also in this case be explained by the differences in complexity of the various measures.

Table 7:7. Distribution of emission control costs between various processes within the chemicals recovery sector

Type of operation	Type of process	Production capacity	Investment expenditure	Subsidy	Total annualized cost	Annualized cost per ton	Red. in annualized costs due to subidies
		10^3 tons/ /year	10^3 S Cr	%	10^3 S Cr	S Cr/ton	
Chemicals recovery at sulphite mills	SI	403	78,575	39	20,182.1	50.08	24.7
Improvements of evaporation	SA	1,080	17,079	44	3,195.5	2.96	38.5
Treatment of gases & condensates	SA SI	897	15,190	64	5,659.9	6.31	27.7
Treatment of gases from soda recovery boilers	SA SI	1.275	14.389	44	6.040.4	4.73	16.9
Stripping columns	SA SI	485	4,240	47	1,266.3	2.61	25.7
Unspecified	SA SI		16.874		4,471.2		
Total		5,530	146,347	45	40,815.4	7.38	25.9

Total discharges of suspended solids were reduced by at least 32,400 tons/year (97.1 tons/day) and the total reduction of BOD_7-discharges by at least 14,300 tons/year (43.0 tons/day).

7.3.6 Summary

The capital expenditures made for emission control purposes in the Swedish pulp and paper industry between July 1, 1969 and July 1, 1973 amounted to approximately 472 million S.Cr. Close to 44 % of these capital expenditures were financed by government subsidies thereby lowering the annualized costs from 116.8 million to 85.4 million S.Cr. (a reduction by roughly 27 %).

With a total pulp production of roughly 8.9 million tons in 1973, the costs incurred for emission conrrol purposes between July 1, 1969 and July 1, 1973 represented an addition to production costs by roughly 13.1 S.Cr. per ton of pulp for the industry as a whole. This cost increase corresponded to approximately 1.5 % of the 1973 average selling price for Swedish pulp. By the subsidies these costs were reduced to about 9.6 S.Cr. per ton of pulp. The distribution of the capital expenditures, the annualized costs, and the discharge reductions between the different sub-processes is shown in Table 7:8. van [illegible]

7.4 ANALYSIS OF EMISSION CONTROL COSTS AT THE PLANT LEVEL

In the chapter on the emission control costs in the iron and steel industry (Chapter 6) it was argued that since the sub-processes (as well as most of the treatment processes) of iron and steel production are relatively independent, the iron and steel industry was analytically "simple". As pointed out in that chapter, however, there were, in spite of the analytical "simplicity", some difficulties associated with the allocation of emission control costs between different residuals.

In the pulp and paper industry, which is an analytically "complex" industry, the allocation of joint emission control costs is even more difficult. As pointed out in the technical description of the production processes, pulp and paper production is a more integrated process and there is, consequently, a higher degree of interdependency between the various sub-processes and treatment processes. Thus, for many sub-processes, neither the amounts of residuals generated nor the character-

Table 7:8. Summary of costs and effects of the emission control measures undertaken by the Swedish pulp and paper industry between July 1, 1969 and July 1, 1973

Processing step	Prod. capacity 10^3 tons/ year	Capital expenditures 10^3 S.Cr.	Subsidy %	Cost reduction due to subsidies %	Total annualized costs 10^3 S.Cr.	Cost/ ton S.Cr./ ton	Type of residial	Minimum total discharge reduction	
								Tons/year	Tons/day
Raw material prep.	1,910	9,440.9	43.4	66.3	1,459.5	0.76	Susp.solids	9,800	26.7
							BOD$_7$	>5,790	>17,4
Pulping (incl. wash.)	3,554	65,761.2	39.1	30.8	13,603.5	3.83	Susp.solids	>25,500	>76.5
							BOD$_7$	>12,270	>36.8
Bleaching	707	14,843.0	51.0	22.6	5,456.8	7.72	Susp.solids	5,000	15.0
							BOD$_7$	5,200	15,4
Recovery of chem.	5,530	146,347.0	45.0	25.9	40,815.4	7.38	Susp.solids	>8,650	>26.0
							BOD$_7$	>27,350	>82.0
							Particulates	>3,700	>11.1
							SO_2	>18,350	>55.1
							H_2S	>1,865	>5.6
Service	3,453	16,251.9	38.2	29.7	4,073.9	1.18	Particulates	>8,100	>24.3
Final sedimentation	4,083	118,240.8	50.3	24.3	28,918.0	7.47	Susp.solids	>32,400	>97.1
							BOD$_7$	>14,300	>43.0
Other measures		31,729.2			10,106.0				
Total	7,127	402,614.0	45.8		104,433.1	14.65	Susp.solids	>81,350	>241.3
							BOD$_7$	>64 910	>194.6
							Particulates	>11,800	>35.4
							SO_2	>18,350	>55.1
							H_2S	>1,865	>5.6

istics of the residuals are independent of the design and/or operating conditions of other sub-processes. The existence of such interdependencies reduces the possibilities to overcome the problem of joint cost allocation by means of a disaggregation of the production process. This raises the interesting question to what extent it is possible to draw any general conclusions from an analysis at the plant level (which might be regarded as the smallest fully separable unit level).

In Table 7:9, the total annualized costs of reducing discharges of suspended solids and organic substances (expressed in BOD_7) have been allocated between the individual plants. As can be seen from this table, there is no clearcut relationship between the size of the plant and the treatment cost per ton of product. If the plants are divided into three main categories (groundwood, sulphite, and kraft mills) it is possible to find some (weak) indications that the treatment cost per ton of pulp varies inversely with the size of the plant. Another observation is that the average treatment costs per ton of pulp in the sulphite pulp industry (approx. 31 S.Cr./ton) is twice that of the kraft pulp industry and almost six times that of the groundwood industry.

The discharge reductions from the production capacity existing in 1969 (roughly 127 thousand tons of suspended solids and 144 thousand tons of BOD_7) were partly offset by the discharges from the additional production capacity installed during the period and the actual reductions of discharges from the pulp and paper industry amounted to approximately 121 thousand tons/year of suspended solids and 120 thousand tons/year of BOD_7. Coastal mills accounted for only about 45 % of the total SS-reduction and 48 % of the total BOD_7-reduction in spite of the fact that these mills accounted for more than 62 % of total pulp production. One inland mill (Skoghall) accounted for roughly 37 % of the total SS-reduction and 43 % of the total BOD_7-reduction.

In a final table, Table 7:10, the total annual costs of the emission control measures undertaken in the Swedish pulp and paper industry are allocated between plants. The table also includes an allocation of total capital expenditures and subsidies. The data indicate that the subsidies have had a greater cost reducing effect in the pulp and paper industry than in the iron and steel industry and that the cost reducing effects have been slightly higher for the sulphite pulp mills than for the other types of mills. There are also some indications that smaller plants (i.e. plants with an annual production capacity under 100,000 tons) on the average have incurred higher costs per ton of pulp than the larger ones. The data also show, however, that in spite of the fact that the ten biggest plants (accounting for roughly 53 % of total production capacity in 1969) received about 59 % of total subsidies, the degree of subsidization was somewhat higher for the plants with an annual production capacity of 100,000 tons (average rate of subsidization ≈ 48.7 %) than for those with a higher production capacity (average subsidization rate ≈ 43.7 %). As far as the cost-reducing effects of the subsidies were concerned, however, they were substantially higher in the small plants (with an average reduction of annual costs by over 34 %) than in the larger plants (average 22.5 %). Since, in the pulp and paper industry, the smallest plants are generally also those with the oldest technology, the subsidies seem to have had led to a certain "preservation" of old technology in the industry.

Table 7:9. Annual costs of reducing discharges of waterborne residuals at ~~individual~~ Swedish pulp and paper mills.

Code	Plant	Type of prod.	Location	Production capacity		Raw residual load kg/ton	Discharges		Discharge-reductions		Annual costs	
				(1969) 10^3 tons/year	(1975) 10^3 tons/year		(1969) kg/ton	(1975) kg/ton	kg/ton	tons/year	10^3 S.Cr.	S.Cr./ton
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
2	Ohs bruk	SIB	I	9	9	SS: 16.9 BOD_7: 311.1	16.9 311.1	4.4 104.0	12.5 207.1	113 1,864	447.4	49.71
6	Fridafors	GR	I	12	15	SS: 81.6 BOD_7: 30.1	79.2 30.0	8.5 17.6	70.7 12.4	1,061 186	508.7	42.39
10	Örebro	GR	I	25	25	SS: 93.4 BOD_7: 38.7	32.0 21.8	6.7 12.8	25.3 9.0	633 225	439.2	17.57
11	Rockhammar	GR	I	27	27	SS: 30.8 BOD_7: 46.8	0.6 37.9	0.6 12.4	– 25.5	– 689	133.2	4.93
13	Billerud	SI SIB	I	15 15	15 15	SS: 92.5 BOD_7: 90.7	68.9 89.1	4.8 60.0	64.1 29.1	1,923 873	2,462.4	82.08
14	Djupafors	GR	I	20	(40)	SS: 10.4 BOD_7: 8.3	10.0 8.0	1.6 3.6	8.4 4.4	168 88	285.0	14.25
15	Lessebo	SIB	I	19	30	SS: 108.1 BOD_7: 154.1	73.1 144.8	6.7 35.5	66.4 109.3	(1,262) (2,077)	1,639.8	86.31
17	Fors	GR	I	36	36	SS: 37.8 BOD_7: 8.4	37.8 8.4	1.1 3.1	36.7 5.3	1,321 191	665.5	18.49
20	Åmotsfors	SA	I	40	40	SS: 63.8 BOD_7: 77.8	53.7 68.1	7.2 25.0	46.5 43.1	1,860 1,724	2,055.3	51.38
22	Clemensnäs	GR	C	40	40	SS: 42.0 BOD_7: 100.2	42.0 100.2	21.8 62.6	20.2 37.6	808 1,504	181.6	4.54
24	Billingsfors	SAB	I	45	45	SS: 31.0 BOD_7: 38.9	31.0 38.9	23.9 20.4	7.1 18.5	320 833	2,077.7	46.17

Table 7:9, cont.

Code	Plant	Type of prod.	Location	Production capacity (1969) 10^3 tons/ year	Production capacity (1975) 10^3 tons/ year	Raw residual load kg/ton	Discharges (1969) kg/ton	Discharges (1975) kg/ton	Discharge-reductions kg/ton	Discharge-reductions tons/year	Annual costs 10^3 S.Cr.	Annual costs S.Cr./ ton
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
27	Broby	SI	I	60	60	SS: 26.8 BOD_7: 35.2	8.1 24.5	3.3 18.9	4.8 5.6	288 336	311.2	5.19
29	Bäckhammar	SA	I	60	125	SS: 50.0 BOD_7: 40.4	50.0 40.4	50.0 27.2	- 13.2	- (792)	176.0	2.93
32	Bureå	GRB	C	65	65	SS: 30.7 BOD_7: 18.0	14.3 12.9	9.5 12.9	4.8 -	312 -	127.3	1.96
33	Deje	SA	I	70	70	SS: 44.3 BOD_7: 17.1	44.3 17.1	21.1 14.9	23.2 2.2	1,624 154	640.1	9.14
34	Olshammar	SAB	I	67	110	SS: 28.4 BOD_7: 58.5	28.4 58.5	20.7 13.8	7.7 44.7	(516) (2,995)	2,447.6	36.53
35	Vallvik	(SI)	C	(70)	175	SS: n.a. BOD_7: n.a.	9.5 28.6	2.8 28.6	6.7 -	(1,173) -	1,333.5	7.12
36	Bergvik	SIB	I	65	80	SS: 46.5 BOD_7:146.7	38.2 146.7	26.1 136.6	12.1 10.1	(787) (657)	1,861.0	23.26
37	Vargön	GRB SIB	I	60 45	60 45	SS: 21.9 BOD_7: 65.5	21.9 65.5	4.8 39.3	17.1 26.2	1,796 2,751	2,030.1	19.33
38	Hörnefors	SIB	C	90	90	SS: 71.9 BOD_7:162.7	65.3 160.9	10.9 108.7	54.4 52.2	4,896 4,698	3,336.2	37.07
39	Ströms bruk	SIB	C	90	90	SS: 112.6 BOD_7:141.9	112.6 141.9	5.0 98.7	107.1 43.2	9,684 3,888	3,207.2	35.64
44	Holmens bruk	GR	C	110	110	SS: 35.3 BOD_7: 13.7	35.3 13.7	29.8 13.7	5.5 -	605 -	148.9	1.35
45	Bowater	GRB	C	115	115	SS: 14.5 BOD_7: 25.2	14.5 25.2	14.5 16.5	- 8.7	- 1,001	67.1	0.58

Table 7:9, cont.

Code	Plant	Type of prod.	Location	Production capacity (1969) 10^3 tons/ year	Production capacity (1975) 10^3 tons/ year	Raw residual load kg/ton	Discharges (1969) kg/ton	Discharges (1975) kg/ton	Discharge-reductions kg/ton	Discharge-reductions tons/year	Annual costs 10^3 S.Cr.	Annual costs S.Cr./ ton
48	Utansjö	SIB GRE	C	55 80 135	55 80	SS: 20.7 BOD_7: 50.9	14.6 50.9	9.6 35.6	5.0 15.3	675 2,066	2,893.9	21.44
51	Wifstavarf	SA GR	C	125 20 145	160 20 80	SS: 17.1 BOD_7: 22.9	14.4 20.1	4.0 0.1	10.4 20.0	(1,508) (2,900)	1,528.3	10.54
52	Göta	SI GRB	I	30 115 145	30 210	SS: 16.9 BOD_7: 28.5	16.9 28.5	2.9 23.0	14.0 5.5	(2,030) (798)	599.3	4.13
53	Köpmanholm	SAB	C	145	145	SS: 18.5 BOD_7: 53.5	12.2 53.5	9.4 47.4	2.8 6.1	406 885	2,486.4	17.15
54	Korsnäs	SAB	C	150	500	SS: 21.7 BOD_7: 30.2	5.7 21.0	4.7 19.0	1.0 2.0	(150) (300)	3,490.2	23.27
60	Östrand	SAB	C	200	255	SS: 65.1 BOD_7:102.0	18.2 102.0	13.5 26.3	4.7 75.7	(940) (15,140)	3,032.4	15.16
62	Domsjö	SIB	C	225	250	SS: 79.8 BOD_7: 69.3	79.6 55.1	11.2 29.2	68.4 25.9	(15,390) (5,828)	4,194.8	18.64
63	Hylte	SIB GR	I	50	100 130	SS: 101.5 BOD_7:214.6	101.5 214.6	3.2 6.9	98.3 207.7	(4,915) (10,385)	2,210.8	44.22
65	Dynäs	SA GR	C	180 70 250	180 70	SS: 32.6 BOD_7: 33.9	21.4 33.9	13.6 28.3	7.8 5.6	1,950 1,400	1,080.9	4.32
67	Iggesund	SAB	C	320	320	SS: 46.1 BOD_7: 36.5	44.6 36.5	23.3 11.0	21.3 25.5	6,816 8,160	2,740.2	8.56
68	Timsfors	SA GR	I	70	(270) 70	SS: 4.8 BOD_7: 7.7	1.0 2.9	(1.3) (3.9)	(-0.3) (-1.0)	(-21) (-70)	(380.1)	5.43
71	Skoghall	SIB SAB	I	75 250	75 330	SS: 154.6 BOD_7:178.7	142.4 153.5	3.3 16.5	139.1 137.0	(45,208) (44,525)	10,116.5	31.13

Table 7:9, cont.

Code	Plant	Type of prod.	Location	Production capacity (1969) 10^3 tons/ year	Production capacity (1975) 10^3 tons/ year planned:	Raw residual load kg/ton	Discharges (1969) kg/ton	Discharges (1975) kg/ton in the old plant -	Discharge-reductions kg/ton	Discharge-reductions tons/year	Annual costs 10^3 S.Cr.	Annual costs S.Cr./ ton
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
72	Ortviken	SI GR	C	82 260	82 330	SS: 31.1 BOD_7: 38.1	8.6 38.1	8.6 26.7	- 11.4	- (3,876)	2,560.8	7.53
73	Skutskär	SIB SAB	C	80 240		SS: 28.6 BOD_7: 75.4	23.5 75.4	10.0 54.1	13.5 21.3	4,320 6,816	1,965.7	6.14
75	Kvarnsveden	GR SI	I	325 72	350 72	SS: 38.4 BOD_7: 27.1	21.3 25.9	11.8 25.9	9.5 -	(3,753) -	402.6	1.02
76	Hallstavik	GR SIB	C	360 60		SS: 44.9 BOD_7: 25.7	10.7 25.7	10.2 14.7	0.5 11.0	210 4,620	4,531.9	10.79
77	Husum	SAB	C	495		SS: 26.6 BOD_7: 57.5	26.6 57.5	10.7 46.6	15.9 10.9	7,871 5,396	4,288.4	8.66
78	Gruvön	GR SAB	I	180 400		SS: 23.0 BOD_7: 24.2	4.3 24.2	4.3 19.1	- 5.1	- 2,958	2,636.5	4.55
Total				5,980	7,427	SS 9 nivå BOD_7 9 nivå			21.3 24.0	(127,292) (143.579)	76.521.1	12.80

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9 ange kg/ton i genomsnitt

bägge typerna av åtgärder

(both water-and air abatement

individual

Table 7:10. Total annual costs ~~of emission control measures~~ undertaken at Swedish pulp and paper plants between July 1, 1969 and June 30, 1973

Code	Plant	Type of prod.	Location	Prod. capacity (1969) 10^3 tons/ year	Total capital expen- ditures 10^3 S.Cr.	Total subsidies 10^3 S.Cr.	Total annual costs (gross) 10^3 S.Cr.	Total annual costs (gross) S.Cr./ ton	Percent reduc- tion of annual costs % efter de subsidier
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
2	Ohs bruk	SIB	I	9	2,500	1,875	447.4	49.71 ✓	68.1
6	Fridafors	GR	I	15	2,055	513	508.7	33.91	16.4
10	Örebro	GR	I	25	2,200	1,100	439.2	17.57	37.2
11	Rockhammar	GR	I	27	470	235	143.5	5.31	26.6
13	Billerud	SI SIB	I	15 15	13,062*	6,718	3,535.6	117.85 ✓	30.9
14	Djupafors	GR	I	30	1,315	660	285.0	9.50	37.7
15	Lessebo	SIB	I	30	10,650*	7,038	3,214.0	107.13 ✓	35.6
17	Fors	GR	I	36	2,250	565	665.5	18.49	13.7
20	Åmotfors	SA	I	40	10,013	4,989	2,239.9	56.00 ✓	34.3
22	Clemensnäs	GR	C	40	1,830	1,114	440.0	11.00	41.1
24	Billingsfors	SAB	I	45	6,880	1,940	2,077.7	46.17 ✓	18.5
25	Kyrkebyn	SIB	I	46	6,600*	4,950	943.3	20.51	85.4
27	Broby	SI	I	60	4,079	1,779	875.3	14.59	33.1
29	Bäckhammar	SA	I	60	551	139	184.1	3.07	12.3
30	Böksholm	SIB	I	60	5,640	1,408	1,596.5	26.61	14.4
32	Bure	GRB	C	65	590	295	152.6	2.35	22.0
33	Deje	SA	I	67	2,464	1,232	655.6	9.79	30.6
34	Ohlshammar	SAB	I	67	10,034	5,932	2,447.6	36.53	39.4
35	Vallvik	SAB	C	68	5,475	2,740	1,464.4	21.54	30.4
36	Bergvik	SIB	I	70	32,840*	10,055	5,701.0	81.44 ✓	30.4
37	Vargön	GRB SIB	I	80	8,213	3,053	2,030.1	25.38	24.5
38	Hörnefors	SIB	C	90	27,000	14,750	6,462.5	71.81 ✓	37.1
39	Ströms bruk	SIB	C	90	12,240	9,200	3,207.2	35.64	48.2
44	Holmens bruk	GR	C	110	675	294	148.9	1.35	23.3
45	Bowater	GRB	C	115	122	61	67.1	0.58	14.8
8	Utansjö	SIB GRB	C	55 80	15,500	5,040	2,893.9	21.44	28.0
49	Frövifors	SAB	I	140	11,096	3,682	2,616.3	18.69	26.0

inte inräknad

Table 7:10, cont.

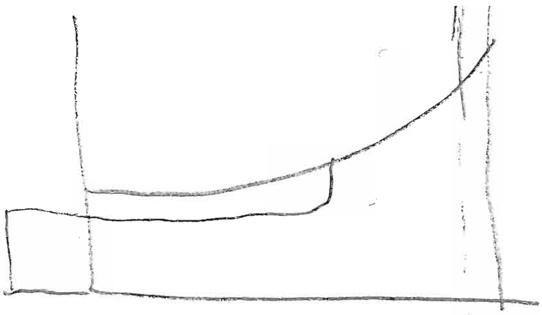
Code	Plant	Type of prod.	Location	Prod. capacity (1969) 10^3 tons/ year	Total capital expen- ditures 10^3 S.Cr.	Total subsidies 10^3 S.Cr.	Total annual costs (gross) 10^3 S.Cr.	Total annual costs (gross) S.Cr./ ton	Percent reduc- tion of annual costs %
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
51	Wifstavarf	SA GR	C	145	9,922	3,155	2,470.3	17.04	20.8
52	Göta	SI GRB	I	145	2,237	1,128	621.8	4.29	30.4
53	Köpmanholmen	SAB	C	145	9,350	4,675	2,681.0	18.49	28.4
54	Korsnäs	SAB	C	150	18,300	6,853	3,502.1	23.35	31.9
59	Karlsborg	SAB	C	197	10.002	2,878	2,057.1	10.44	19.4
60	Östrand	SAB	C	200	14,832	6,246	3,289.9	16.45	30.9
61	Munksund	SA	C	210	5,353	3,467	1,950.6	9.29	28.9
62	Domsjö	SIB	C	225	17,969	9,090	5,394.0	23.97	26.2
63	Hylte	SIB GR	I	100 130	9,040	2,620	2,210.8	9.61	19.3
65	Dynäs	SA GR	C	180 70	3,000	1,993	1,351.3	5.41	27.1
67	Iggesund	SAB	C	265	9,971	7,479	2,740.2	10.34	44.4
68	Timsfors	GR	I	70	1,285	643	381.1	5.43	27.5
71	Skoghall	SIB SAB	I	325	17,624	10,480	9,090.2	27.97	12.9
72	Ortviken	SI GR	C	340	11,500	5,625	3,376.6	9.93	27.1
73	Skutskär	SIB SAB	C	350	9,500	7,125	2,301.8	6.58	50.4
74	Lövholmen	SA	C	350	6,453	1,678	2,157.6	6.16	12.6
75	Kvarnsveden	GR SI	I	325	2,454	1,128	616.3	1.56	32.4
76	Hallstavik	GR SIB	C	360 60	17,432	3,453	4,531.9	10.79	12.4
77	Husum	SAB	C	495	18,957	9,462	4,760.9	9.62	32.7
78	Gruvön	GR SAB	I	180 400	11,089	3,910	3,505.7	6.04	18.1
Total				7,127	402,614	18,445	104,433.1	14.65	

47 ?

Number of plants = 47

CHAPTER 8

SUMMARY AND CONCLUSIONS



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8.1 RECAPITULATION OF THE OBJECTIVES OF THE STUDY

As pointed out in Chapter 3, the present study had two major objectives. The primary objective was to try to specify the emission control costs incurred by the Swedish iron & steel and pulp & paper industries between July 1, 1969 and July 1, 1973 in such a way that these cost data could serve as a basis for environmental policy decisions. A secondary objective was to assess the economic and environmental impact of Swedish environmental policy between July 1, 1969 and July 1, 1973.

By the help of a simple economic model it was shown in Chapter 3 that the level of emission control was optimal when marginal social costs of an additional reduction of discharges just equalled the corresponding marginal social benefits. In the crudest version of this model, it was assumed that there was only one residual and that the costs of reducing the discharges of this residual were completely separable from other costs. Both assumptions are of course highly questionnable from an empirical point of view. The assumption of a single residual could be accepted if the decision-maker had a set of weights (preferable reflecting marginal social damage) by the help of which the different residuals could be expressed in a common unit. The fact that a number of environmental policy decisions already have been taken, implies that some kind of weighting procedure has been used. Unfortunately, the set of weights actually used by the decision-maker, is not known (perhaps not even by himself!).

The assumption of separability of emission control cost is difficult to maintain even if there is only one residual. When emission control measures consist of the installation of "add-on" treatment equipment, one can fairly well identify the costs. In those cases where the control measures take the form of process changes, however, it is generally quite difficult to identify that part of the total annual costs which should be classified as emission control costs.

This problem of joint cost allocation is complicated further in those cases where there are several residuals. This is due to the fact that many treatment processes reduce the discharges of more than one residual at a time. As pointed out in Chapter 3, emission control costs should, in order to be of maximum use to the decision-maker, be expressed per kg of discharge reduction. In the case of "joint treatment" it is not possible to allocate the treatment costs between the different residuals without a set of weights.

In Chapter 3 it was argued that the joint cost allocation problems associated with the joint treatment of several residuals at a time might be partly overcome by a disaggregation of the production process into its various components (i.e. subprocesses). This was, consequently, the methodology followed in Chapters 6 and 7.

8.2 THE QUALITY OF THE EMISSION CONTROL COST DATA

Before discussing the different uses to which the emission control cost data could be put and the conclusions which possibly might be drawn, there are a number of important points which have to be made concerning the quality of the data.

The first point refers to the fact that the present study only covers the additional costs incurred for emission control between July 1, 1969 and July 1, 1973 by plants already in operation by July 1, 1969. Thus, no emission control costs by new plants were included. Since the number of entirely new plants constructed during the period under investigation was quite small, however, this omission does not constitute any major drawback.

A second point concerns the fact that a number of plants which were in operation by July 1, 1969 expanded their capacity during the period under investigation. Since the data base for the present study consisted of the applications for government subsidies and the directives of the subsidization scheme stated that emission control measures reducing discharges from new production capacity would not be entitled to any subsidies, the cost data presented in the present study do not cover the full additional costs incurred by the included plants but only that part of the additional costs which refers to the pre-July 1, 1969 capacity. This has some implications for the possibilities to fulfill the secondary objective of the study, i.e. to assess the economic impact of the emission control measures undertaken between July 1, 1969 and July 1, 1973 by the iron & steel and pulp & paper industries. For a fulfillment of this objective it would also have been desirable for the study to cover the whole original subsidization program, i.e. July 1, 1969 to June 30, 1974. The reason for not including the last year of the original subsidization program was the fact that the data collection proved to be much more time consuming than expected. Since budgetary constraints made it impossible to prolong the study, it was decided to limit the study to the period July 1, 1969 - July 1, 1973. It should perhaps be pointed out that preliminary figures indicate that the capital expenditures for emission control purposes between July 1, 1973 and July 1, 1974 amounted to roughly 166 million S.Cr. (approximately 25 % of which were subsidies) in the pulp and paper industry and to around 60 million S.Cr. (36 % of which were subsidies) in the iron and steel industry. This means, in fact, that the period chosen for analysis does not cover more than about 75 % of total subsidized capital expenditures for emission control purposes during the original period of government subsidization. In view of the partial nature of the present study, therefore, conclusions concerning the economic impact on the two industries of the environmental policy program must be drawn with caution.

The shortcomings of the data as far as the fulfillment of the study's secondary objective did not seriously affect the possibilities of fulfilling the primary objective of the study, i.e. presenting the emission control costs incurred by the Swedish iron & steel and pulp & paper industries between July 1, 1969 and July 1, 1973 in a form useful to the decision-maker. In fact, by making the analysis at a disaggregated level, i.e. at the subprocess level, it was possible to rely on cross-section data. As pointed out in Chapters 6 and 7 there were some subprocesses for which the number of observations was insufficient (or the data incomplete), but the difficulties faced by the analysis at the subprocess level were primarily related to the problem of joint cost allocation.

An additional point that has to be raised concerns the reliability of the data. Since operating costs were not always specified in the subsidy applications in some of the cases, the costs (on an annual basis) had to be estimated with the help of engineering data. In order to check the accuracy of these estimates, extensive discussions were held with various industry experts. Thanks to these discussions, certain improvements in the quality of the cost calculations were made.

8.3 USEFULNESS OF THE COST DATA

In order to be able to assess the achievements of the present study, it is useful to discuss in some detail the possible uses to which the data presented in Chapters 6 and 7 could be put.

Consider to begin with the problems faced by those responsible for environmental policy decisions. Their task is not only to choose the "optimal" level of emission control but also to design a policy which will ensure that this level is attained at a minimum cost to society. As pointed out in Chapter 2, most environmental policy programs have as their starting point some more or less well defined environmental quality standards. Furthermore, the most commonly used method of implementing such quality standards has long been to set emission standards for those residuals that were to be controlled. Since an optimal use of emission standards requires not only that the standards are set at such a level that the desired total reduction of emissions is accomplished but also that this reduction is allocated between the different sources in such a way that the costs to society are minimized. A minimization of the total costs of a given reduction of discharges of a particular residual requires that the marginal costs of discharge reductions are equal for all sources. Since it is highly unlikely that treatment cost functions should be equal for all sources, optimal emission standards would have to differ not only between different processes but also between different subprocesses.

Availability of emission control cost data at a disaggregated level should enable the policy-maker to evaluate the existing set of standards with regard to the cost-minimization objective. Although the cost data presented in Chapters 6 and 7 should be interpreted as "additional costs" rather than "marginal costs" they could still be useful to the decision-maker. For example, an analysis of the cost per kg of reduction of particulate discharges in the iron and steel industry reveals that there are substantial differences between the various subprocesses. If these cost figures were to be treated as at least rough approximations of the marginal costs, these differences would indicate an inefficient allocation of discharge reductions between the various subprocesses. This would mean that some savings might be attained by tightening the restrictions on discharges for some subprocesses simultaneously with a relaxation of the restrictions for some others. In this specific case it would mean that restrictions should be tightened for the particulate emissions from the casting shops and the basic oxygen furnaces, and relaxed for emissions from the electric arc furnaces.

Needless to say, there are numerous reasons to be careful with such conclusions. Apart from the fact that the cost figures refer to "non-marginal" discharge reductions and that treatment costs display large variations between plants, there might be certain other obstacles to a successful reallocation of discharge reductions. In order to achieve a reduction of total treatment costs by adjustments in emission standards, however, it is necessary to assume that treatment cost functions are continuous in the relevant ranges. There are clear indications, however, that such an assumption cannot readily be made for all subprocesses. The particulate emissions from the basic oxygen furnaces, for example, are generally subjected to treatment methods with collection efficiencies of over 95 %, and a tightening of the emission standard of 0.3 kg/ton for this kind of furnace would not only be very costly but also contribute rather little to the total discharge reductions from the iron and steel industry. In fact, even a 100 % reduction of particulate emissions from this type of furnace would increase the daily discharge reduction by only between 0.6 and 2.0 tons/day.

As far as the particulate emissions from the casting shops are concerned, the situation is slightly different. Since approximately 80 % of the Swedish raw steel production is cast in moulds, a further increase in the reduction of particulate emissions from the casting shops might increase the daily discharge reduction by around 14 tons. Even a reduction by half of that amount (which to a large extent might be accomplished by improvements of hoods and fans) would seem worthwhile in view of the 1.5 to 3.0 tons of additional daily discharge reduction that will be the result of the announced tightening of the emission standard for the electric arc furnaces in 1978 (i.e. from 1.0 to 0.6 kg of particulates per ton of raw steel). This is even more so in view of the fact that compliance with this lower emission standard in most cases would necessitate the quite costly method of total building evacuation.

Thus, even if the cost data presented in Chapters 6 and 7 do not permit any definite conclusions concerning the possibilities for cost savings by means of adjustments of the existing set of emission standards, they indicate in which directions such cost savings might be sought. Perhaps, then, the primary benefit of the present study consists of developing a methodology for identification of emission control costs in the iron & steel and pulp & paper industries and of pointing out where major difficulties are likely to rise.

In spite of the fact that the cost data presented in Chapters 6 and 7 do not cover all costs incurred for emission control in the two industries, these data can still be used for some tentative conclusions concerning the economic impact at the plant and industry level of an environmental control program of the Swedish type. As pointed out in Chapters 6 and 7, the additional costs incurred for emission control purposes in the iron & steel and pulp & paper industries amounted to roughly 13.2 and 14.7 S.Cr./ton respectively. Since emission control was not an entirely new thing to these industries, most plants were already incurring some costs for emission control at the beginning of the period under investigation. Under the assumption (based on a so-called "informed guess") that these costs were at a level roughly half of the additional costs incurred during the period under investigation, the present level of emission control costs would be around 20 S.Cr./ /ton in the iron & steel industry and around 22 S.Cr./ton in the pulp & paper industry. These cost levels correspond to approximately 1.6 and 2.6 % of the average 1973 selling price, respectively. There were, of course, substantial variations between plants, and the data presented in Chapter 7, section 7.4, indicated, for example, that the treatment costs in the sulfite industry were substantially higher than in the kraft (sulfate) and groundwood industries. In the pulp & paper industry there was also a tendency for the smaller plants to incur higher treatment costs than the larger ones. Another interesting observation that could be made from the data presented in section 7.4 was that the average rate of subsidization was somewhat higher for plants with an annual production capacity of less than 100,000 tons (48.7 %) than for plants with a higher production capacity (43.7 %). The cost-reducing effect of the subsidies was, however, substantially higher in the small plants with an average reduction of annual costs by over 34 % compared to a reduction by only 22.5 % in the larger plants. Under the assumption that there is a negative correlation between age (i.e. technology) and size of plants, the data would thus seem to indicate that the subsidies, to a certain extent, have had the effect of "preserving" old technology in the industry. The long-run effect of a preservation of old processing technology is probably a deterioration of the industry's international competitiveness, which, in view of the large share of pulp and paper production that is exported, would be serious not only for the industry but also for the country as a whole.

8.4 CONCLUSIONS

As evident from the discussion in the preceding section, the cost data presented in Chapters 6 and 7 can, in spite of their partial character, form the basis for some interesting analyses concerning the economic impact of the environmental policy decisions made during the period under investigation. The numerous difficulties and limitations associated with the data have been brought out at various stages of the presentation. In this section, therefore, an attempt will be made to evaluate the usefulness of the present study and to assess the extent to which it has achieved its objectives.

The main achievement of the study lies in the demonstration of the merits and dismerits of the methodology of disaggregating the production process for the analysis of emission control costs. The argument behind this methodology was that the joint cost allocation problems arising in the cases of joint treatment of several residuals might be partly overcome. Due to the fact that the different subprocesses of the iron and steel industry were more easily separable than those of the pulp and paper industry, the chosen methodology proved more successful in the former. Thus, in the iron and steel industry it was possible to identify the costs for reductions of particulate discharges and present them in the desirable form. The methodology's limited success in the analysis of emission control costs in the pulp and paper industry put emphasis to the fact that the estimation of the damage associated with residuals discharges can never be completely avoided. Thus, in the absence of weights (preferably reflecting marginal damage) by the help of which the economist can allocate joint costs of residuals treatment, there will be no treatment cost functions of the type depicted in standard economic theory.

As far as the study's secondary objective is concerned, the study could only claim moderate success. As pointed out at various stages, the partial character of the data made a complete assessment impossible. Nevertheless, the data presented in Chapters 5-7 contained enough information to allow at least some tentative conclusions about the economic and environmental impact of the Swedish environmental policy during the period under investigation. Thus, the data seemed to indicate that the set of emission standards for individual sub-processes was not promoting an optimal distribution of discharge reductions within the plants and the observed costs for emission control could probably not be regarded as minimum costs forthe given discharge reductions. This conclusion is probably reinforced by the effects of the increased subsidies. Since these subsidies were tied to certain time-limits, they tended to make the plant managers more time-conscious than cost-conscious. In addition, temporary shortages of treatment equipment served to inflate the prices on such equipment. From an efficiency point of view, the subsidization scheme seem to have "aggravated" the situation further by "preserving" older technology. This might in the long run adversely affect the international competitiveness of the industries - an effect which can hardly have been desired by the decision-makers.

As far as the total effects on discharges were concerned, it was possible to get an overall impression of the achievements during the period in question. Due to the above-mentioned limitations at the data (and the methodology!) it was not possible to allocate the total discharge reductions completely between the various sub-processes. In view of the substantial informative value contained already in the aggregated figures, this shortcoming of the data did not seriously reduce the value of the study.

Thus, even if the primary objectives of the study have been only partially fulfilled, sufficient amounts of valuable information have been brought forward to make the study worth while. The study has, in addition, raised a number of theoretical as well as empirical problems which will soon have to be solved by economists and social scientists. Even if the solution of these problems might constitute a small step in the advance of the science of economics, it will constitute a giant leap to any individual economist.

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