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A FRAMEWORK FOR TECHNOLOGICAL CHOICE (A TECHNOLOGY ASSESSMENT: METHODOLOGY FOR THE CHOICE OF WASTEWATER TREATMENT FACILITIES)*

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ABSTRACT

In this article, technological assessment is defined as a multidimensional process as applied to a management model in order to make wise or "best" choices. A method of technological assessment is presented as well as its application to the choice of wastewater technology. An analysis of the critical path used in the Québec urban wastewater treatment program was done using a grid made up of six dimensions, or domains, that can be considered when making a technology assessment study (technology, economics, environment, society, the individual, values and collective aspects of decision-making). This led to the identification of the most important criteria on which the selection of technologies was based: it was found that technical, economic, and environmental criteria were called upon much more often than those relating to society, the individual, or to values and collective aspects of decision-making.

INTRODUCTION

The basis for action is decision. However, the decision-making process is in itself extremely complex: many interacting factors modulate the quality of the decision [1], and, consequently, the appropriateness of the resulting action [2]. Among these factors, technology assessment must be part of the planning process and therefore lead to the selection of an optimal course of action [3]. According to Mayo [4]:

> "Technology assessment" refers to the identification of the effects (direct and derivative—immediate, intermediate, and long term) and the

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evaluation of the social desirability or undesirability of such effects as related to particular applications.

Following this definition, technology assessment may be characterized as:

1. relating to the implementation of a given technology, be it well established or innovative, with or without regard to competing technologies;
2. identifying the possible impacts following the use of a technology, of its variants, or of any other technology with similar capabilities; and
3. evaluating the acceptability of these impacts with respect to existing (or future) social goals and values.

Thus, technology assessment may be seen as having two distinct, but complementary, aspects: on the one hand we seek to objectively determine the nature of the impacts while, on the other hand, the acceptability of these impacts is based primarily on social values which are, by definition, subjective in nature.

PROBLEM-SOLVING PROCESS

The resolution of problems is a basic human function that has been the object of much scientific inquiry [5]. The problem-solving process may be schematized as illustrated by Figure 1 [6]. In this process, a decision-maker must first identify the problems that his mandate allows him to solve (step 1). Among these problems, he must then establish a list of priorities (A). By defining the problem's components, e.g., the participants or actors and stakes involved, he attempts a representation of the problem (step 2) which will then be evaluated according to a set of pre-determined decision criteria (B). The problem being appropriately defined, the decision-maker may generate various preliminary solutions (step 3) among which, following evaluation (C), one will be selected to be more precisely defined for eventual implementation (Step 4). Finally, the decision-maker must decide if implementation will be carried out (D). By observation of the effects of his intervention, the decision-maker can evaluate his problem-solving process (step 5) and choose, it warranted, to modify the process (E) if its performance is unsatisfactory.

The process, as described here, uses two types of models: representation and decision models. Representation models (steps 1, 2, 3, 4, and 5) contain guidelines for the processing of the available information into an image that the decision-maker can readily understand. Decision models (steps A, B, C, D, and E) enable the evaluation of the representation models with regard to personal or organizational performance criteria: for example, model D (the decision to implement) will define the nature and precision of the information content required before implementation can be considered. If a particular representation model does not satisfy the decision criteria, then additional or different information must be sought.

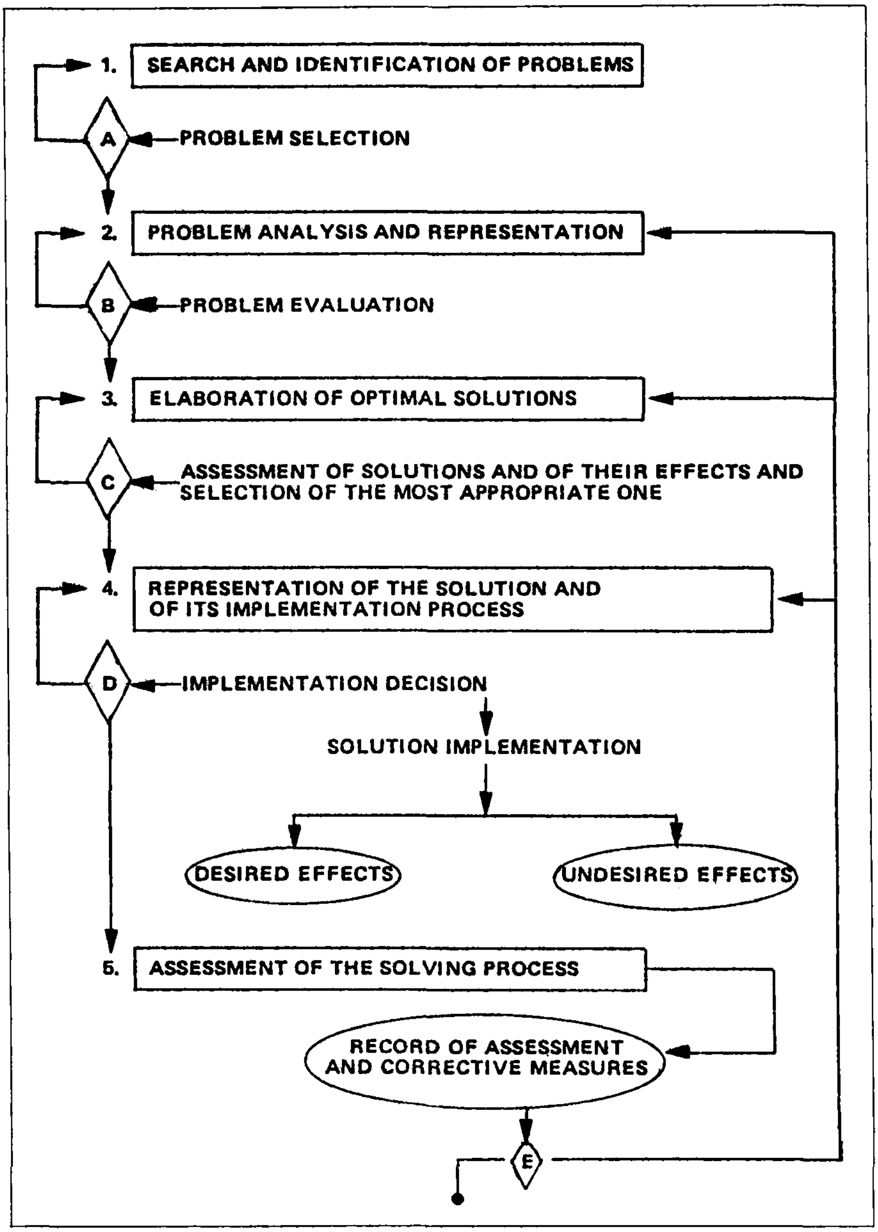

Figure 1. The problem-solving process: steps 1, 2, 3, 4, and 5 are representation models while steps A, B, C, D, and E are decision models.

Table 1. The Office of Science and Technology/MITRE Methodology

Step Number	*Task*
Step 1	Define the Assessment Task – Discuss relevant issues and any major problems – Establish scope (breadth and depth) of inquiry – Develop project ground rules
Step 2	Describe Relevant Technologies – Describe major technology being assessed – Describe other technologies supporting the major technology – Describe technologies competitive to the major and supporting technologies
Step 3	Develop State-of-Society Assumptions – Identify and describe major nontechnological factors influencing the application of the relevant technologies
Step 4	Identify Impact Areas – Ascertain those societal characteristics that will be most influenced by the application of the assessed technology
Step 5	Make Preliminary Impact Analysis – Trace and integrate the process by which the assessed technology makes it societal influence felt
Step 6	Identify Possible Action Options – Develop and analyze various programs for obtaining maximum public advantage from the assessed technologies
Step 7	Complete Impact Analysis – Analyze the degree to which each action option would alter the specific societal impacts of the assessed technology discussed in Step 5

TECHNOLOGY ASSESSMENT SEEN AS A PROCESS

Several technology assessment methodologies have been put forth in the literature (for a brief review, see [7]): the general principles are similar but the number of steps, or phases, required to carry them out may vary from one author to another. The *Office of Science and Technology/MITRE's* seven step methodology may be used here to illustrate these general principles (see Table 1) [8]. Once the assessment task is circumscribed (step 1), the relevant technologies are described (step 2) and the state of society is established (step 3). Next, the possible impacts following a massive implementation of the technology are described (step 4) and evaluated in relation to as many social groups as possible (step 5). Step 6 consists in identifying the action options available while their effects on the societal impacts are assessed in step 7.

DIMENSIONS OF TECHNOLOGY ASSESSMENT

As can be easily imagined, application of a methodology as complex as the one mentioned above requires contributions from many scientific fields (e.g., engineering, ecology, sociology, political science, etc.) if a coherent and complete picture of the effects of a technology's implementation is sought. In this article, the various general fields of scientific inquiry involved in technology assessment will be called *dimensions*. We will see later how these dimensions may be used in characterizing any given technology assessment procedure. We will briefly define here each of the six dimensions that have been retained from the list proposed by Hetman (see Table 2) [9].

Technology

In any attempt at technology assessment one has to understand and characterize the technology involved. The following questions are among the most important:

a. *functional capacity*: knowledge of a technology's uses and limits;
b. *context*: understanding the relations between the assessed technology and its related technologies;
c. *technology improvement*: characterization of the research and development, production, and marketing functions pertaining to the technology;
d. *technology transfer*: inquiries into the uses of a technology in areas other than the one presently perceived;
e. *diffusion*: knowledge of the extent to which a technology is liable to be made available; and
f. *legal constraints*: identification of the laws and regulations to which a technology is subject, at the present time or in the future.

Economics

Economics and technology cannot be easily dissociated: economic parameters (e.g., research and development incentives) play a major role in the development of technologies, which, in turn, have considerable economic impacts (e.g., exports). Some aspects worthy of investigation are:

a. *costs and benefits*: estimating the monetary costs and benefits involved;
b. *innovation process*: identifying the market incentives and interests responsible for the technological development;

c. *industrial structure*: knowledge of the degree of innovativeness (or conservatism), competition, and concentration within the economic sector involved; and
d. *competition structure*: this is important because competition by innovation, e.g., by opening new markets, may be a substitute to competition by pricing in older markets.

Table 2. The Dimensions of Technology Assessment

Dimensions	*Specific Questions*
1. Technology	a. functional capacities b. context c. technology improvement d. technology transfer e. diffusion f. legal constraints
2. Economics	a. costs and benefits b. innovation process c. industrial structure d. competition structure
3. The Environment	a. environmental resources b. ecosystem dynamics c. environmental impacts d. artificial systems
4. Society	a. social sub-systems b. allocation of resources c. social ties
5. The Individual	a. security b. social status c. quality of life
6. Collective Values	a. visibility b. interest groups c. third parties d. the state e. institutional arrangements

The Environment

The restoration and preservation of our environment's quality is rapidly becoming a major preoccupation. The ecological disasters of the recent decades have produced a strong impact upon many, and fewer people today are willing to let technological development go unchecked. Points of interest relate to:

a. *environmental resources*: knowledge of the variety and extent of the resources found in the ecosystem(s) liable to be affected by the technology;
b. *ecosystem dynamics*: understanding the relations, e.g., energy flows, that exist between the various environmental resources;
c. *environmental impacts*: estimating the effects, whether positive or negative, of a technology's implementation on the characteristics of the ecosystem; and
d. *artificial systems*: understanding the interaction between man-made systems (pipelines, transportation networks, cities, etc.) and natural systems.

Society

The social fabric has been greatly modified by the introduction of technologies in the past [1]: the automobile is most certainly the most visible illustration of this. If we seek to minimize the negative social impacts of technological change, the following areas of inquiry merit attention:

a. *social sub-systems*: the identification of a technology's impact on various important societal components such as the labor market or the education system;
b. *allocation of resources*: forecasting the way in which the costs and benefits related to a technology will be distributed among the various social classes; and
c. *social ties*: estimating the likelihood that a technological change will alter the present characteristics of the relations between individuals, e.g., the extent to which the sense of loneliness of people living in urban areas will be enhanced or reduced.

The Individual

At home or at work, technological developments are liable to affect us as individuals. Some aspects to be looked into are:

a. *security*: understanding the possible impacts of a technology on individual health characteristics and life expectancy;
b. *social status*: will a technological change modify the social structure to the extent that an individual's feeling of self-esteem may be affected? This is particularly important when the labor market is modified; and
c. *quality of life*: forecasting the changes in persons' lifestyles following the implementation of a technology [2].

Collective Values

This is the public domain, where the interactions between the various interest groups result in the formulation of policies concerning technological applications. Points of importance are:

a. *visibility*: determination of the degree of publicness of a technological issue;
b. *interest groups*: identifying the groups promoting or opposing the proposed technology, as well as the potential costs and benefits involved for both parties;
c. *third parties*: identifying the groups not active in the public debate but nonetheless liable to bear some costs or reep some benefits;
d. *the state*: understanding the role that government is able and willing to play in the process of technological choice making; and
e. *institutional arrangements*: analyzing the laws, regulations, and administrative procedures that formally define the rules to which the actors must conform.

TECHNOLOGY ASSESSMENT AND PROBLEM SOLVING

The decision-maker is often called to act upon issues with an important technology content. Figure 2 illustrates how technology assessment fits into the problem-solving process presented in the previous section. At step 3, the manager generates solutions which may be derived from many fields: fiscal measures, legal constraints, choice of technology, etc. For the aspects pertaining to technology, the decision-maker refers to the technology assessment procedure warranted by his organization and uses it as a tool within the general solution assessment made at step C. For the other aspects, various other sub-models of C may be used; for example, the fiscal measures may be submitted to a "fiscal assessment procedure, and so on.

Of course, the importance of the technology assessment sub-model in decision model C is related to:

1. the nature of the problem and of its eventual solutions—problems do not always call upon solutions with a large technology content: for example, the elimination of sexist stereotypes from publicity requires less technology than does wastewater treatment; and
2. the number of dimensions considered: unless the problem is very simple, a technology assessment procedure based solely on the technology dimension will occupy a smaller part of model C than one that draws upon all six dimensions proposed above.

When issues have a very important technology content, the integration of the sub-models of C becomes essential. Indeed, Coates writes [10]:

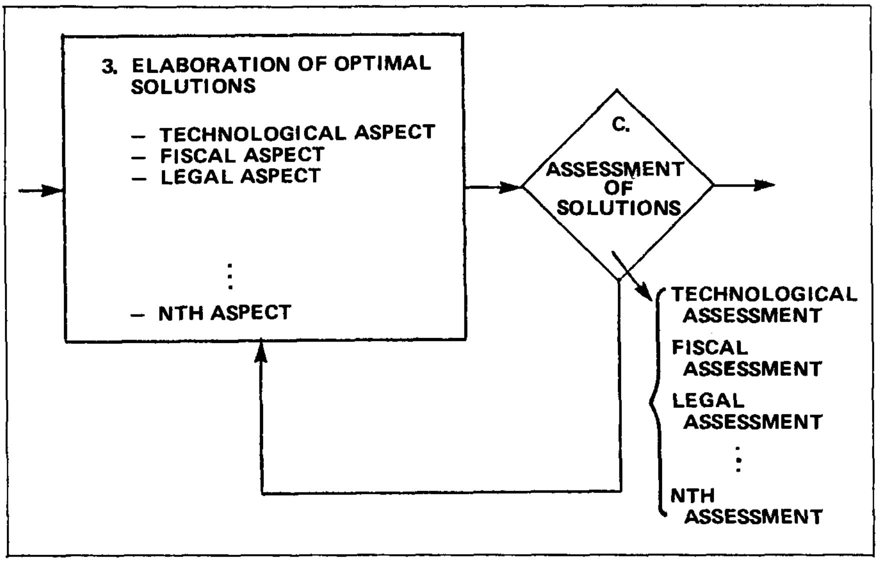

Figure 2. Technology assessment and the problem-solving process (3 and C correspond to 3 and C in Figure 1).

> In many agencies concerned with a technological development, economic analysis is done in one part of the agency, environmental impact analysis in another part, social impact analysis in a third part, and policy formulation somewhere else entirely. Until these activities are integrated to inform the policy-maker, there is no technology assessment no matter how much that term may be used or insisted upon.

In this perspective, to speak of technology assessment when the information from the various sub-models is not integrated is a waste of time. An integrated approach may be facilitated by granting official status to technology assessment and by defining the powers of the involved agencies. the *Office of Science and Technology* created in 1976 (P.L. 94-1040) in the United States, is a case in point.

TYPES OF TECHNOLOGY ASSESSMENT

As mentioned above, the scope of a technology assessment procedure is related to the dimensions taken into account. An attempt is made here to classify some technology assessment procedures (see Table 3) found in the literature with respect to the six dimensions discussed earlier. The classes, as modified from Hetman follow [9].

Table 3. The Types of Technology Assessment

	Dimensions Taken Into Account					
Assessment Type	*Technology*	*Economics*	*The Environment*	*Society*	*The Individual*	*Collective Values*
1. Technical performance	X[a]	X				
2. Cost-benefit analysis	X	X				
3. Market characterization	X	X			Lim.[b]	
4. Global economic cost	X	X		Lim.		
5. Environmental assessment	X	X	X		Lim.	Lim.
6. Technical-social cost-benefit analysis	X	X	X	X		
7. Multi-impact assessment	X	X	X	X	X	
8. Comprehensive assessment	X	X	X	X	X	X

[a] X denotes extensive emphasis.
[b] Lim. denotes limited emphasis.

Technical Performances

Based solely on technical characteristics, the performance of various products are compared and the one having the best performance is chosen.

Cost-Benefit Analysis

Based on technical characteristics and feasibility parameters, this type of assessment establishes the investment and production costs as well as the expected benefits: the technology offering the best cost-benefit ratio is chosen. Such an approach was used in the choice of fossil fuel conversion processes [12].

Market Characterization

The implementation of a technology being taken as virtually unavoidable, an attempt is made to predict the general economic benefits and, indirectly, the benefits perceived by the potential consumers. Cable communications in the United States was subject to such an assessment [12]: apart from estimating economic impacts, some references were made to public segmentation, to teaching uses, etc.

Global Economic Cost

Somewhat similar to cost-benefit analysis, this type of assessment uses a systems approach: the technology is viewed in relation to other components in the economic system. Thus, it is an intersectorial approach taking into account, in an economic perspective, the impacts on, for example, the labor market or the processing of the wastes generated by the use of a technology. Such a study was made to determine the trends in the use of glues in the particle board industry [13].

Environmental Impact Assessment

The objective here is to evaluate the extent and reversability of short- and long-term environmental effects following the implementation of a technology. One very important point, of course, is the definition of what is an acceptable level of environmental contamination. Such procedures are relatively well structured within various government agencies [14, 15].

Technical-Social Cost-Benefit Analysis

In addition to technical, economic, and environmental aspects, this type of assessment is concerned with the impacts on the social groups liable to be affected by a technological change. In planning the *Harbor Islands project in Massachusetts* [9], various criteria pertaining to social groups were taken into account: the increase in the number and types of housing units, the changes in education opportunities, the reduction of middle-class migration to the suburbs, the opinions of interest groups, etc.

Multi-Impact Assessment

This is a wide-spectrum study examining the impacts of a given technology, without necessarily comparing it to other technologies. The problem of noise from subsonic aircraft was tackled in this manner [16, 17] : four types of factors (technical, economic, social, and political) were taken into account when various solution strategies were evaluated.

Comprehensive Assessment

This is an investigation of the full potential of a technology and of its impacts on all sectors of society: its scope is limited only by the data and knowledge available during its execution. The *Office of Science and Technology/MITRE* methodology is an appropriate example of a comprehensive technology assessment [8]. This methodology was applied in a pilot-project on the problem of domestic wastewater technology [18].

CASE STUDY: THE QUÉBEC WASTEWATER CONTROL PROGRAM

Faced with growing deterioration of the aquatic environment, the government of the province of Québec (Canada) established in 1978 its wastewater control program. This public program pursues two main objectives [19]:

1. to "enhance and maintain water quality in order to satisfy uses such as drinking water, swimming, and recreation"; and
2. to "obtain and maintain an aquatic environment suitable for the normal evolution of biological resources."

The implementation of this program will have meant spending approximately six billion Canadian dollars by 1990 [20, 21]. The *Québec Ministry of the Environment* is mandated to carry out the program throughout the province by controlling wastewater production from all agricultural, industrial, and municipal sources. The treatment of municipal wastewaters alone will cost 4.5 billion Canadian dollars of which 2.5 billion is allocated to the construction of treatment plants and 2 billion to the rehabilitation of sewer networks [22]. The provincial government subsidizes to a large extent the construction costs whereas the operation and maintenance costs are the municipalities' responsibility (see Table 4) [23, 24]. (All costs involved in agricultural or industrial wastewater control are borne directly by the polluters.) The main actors involved in the municipal wastewater control program are shown in Table 5; this list is restricted to those that have an official role as to the program's implementation, e.g., contracts signing or plan preparation.

Table 4. Extent of Government Subsidies for the Construction of Municipal Wastewater Treatment Systems, as of June 1983

Eligible Costs	*Government Subsidy*
Sewer network analysis	100%
Wastewater characterization	100%
Treatment plant design and construction	90%
Sewer network rehabilitation	63-2/3% to 90%

Table 5. Main Actors in the Québec Municipal Wastewater Control Program

Québec Government	– Ministry of the Environment – Ministry of Industry, Commerce, and Tourism – Conseil du Trésor (Treasury Board) – Farmland Protection Commission
Municipal Authorities	
Consulting Firms	
Contractors	

The technology assessment procedure uses in 1963 was determined by analyzing the administration procedure (see Figure 3), to which every municipality is subjected before any construction is undertaken [24]. This section is limited to a sketchy overview of the procedure; however, a more detailed account is found in Crowley [25] and Crowley *et al.* [26]. Our analysis enabled the identification of the actors involved at each step of the administrative procedure as well as the technology assessment dimensions taken into account. It was thus possible to add these observations to the official procedure (Figure 3), and to obtain a model of the technology assessment procedure used by the *Québec Ministry of the Environment* (see Figure 4).

Initial programming of the target municipalities is based on environmental and social (demographic) factors. A preparatory study is then made by ministry staff: the technical content of the proposed solution is arrived at on technical, economic, and environmental grounds. The *Treasury Board* approves the technical, economic, and social aspects of the project before negotiations between the ministry and the municipality are undertaken; the latter, in accepting to participate in the program, is preoccupied by technical, economic, and political impacts of wastewater control on its constituents (in rural areas, the *Farmland Protection Commission* is also involved in the siting aspects of the

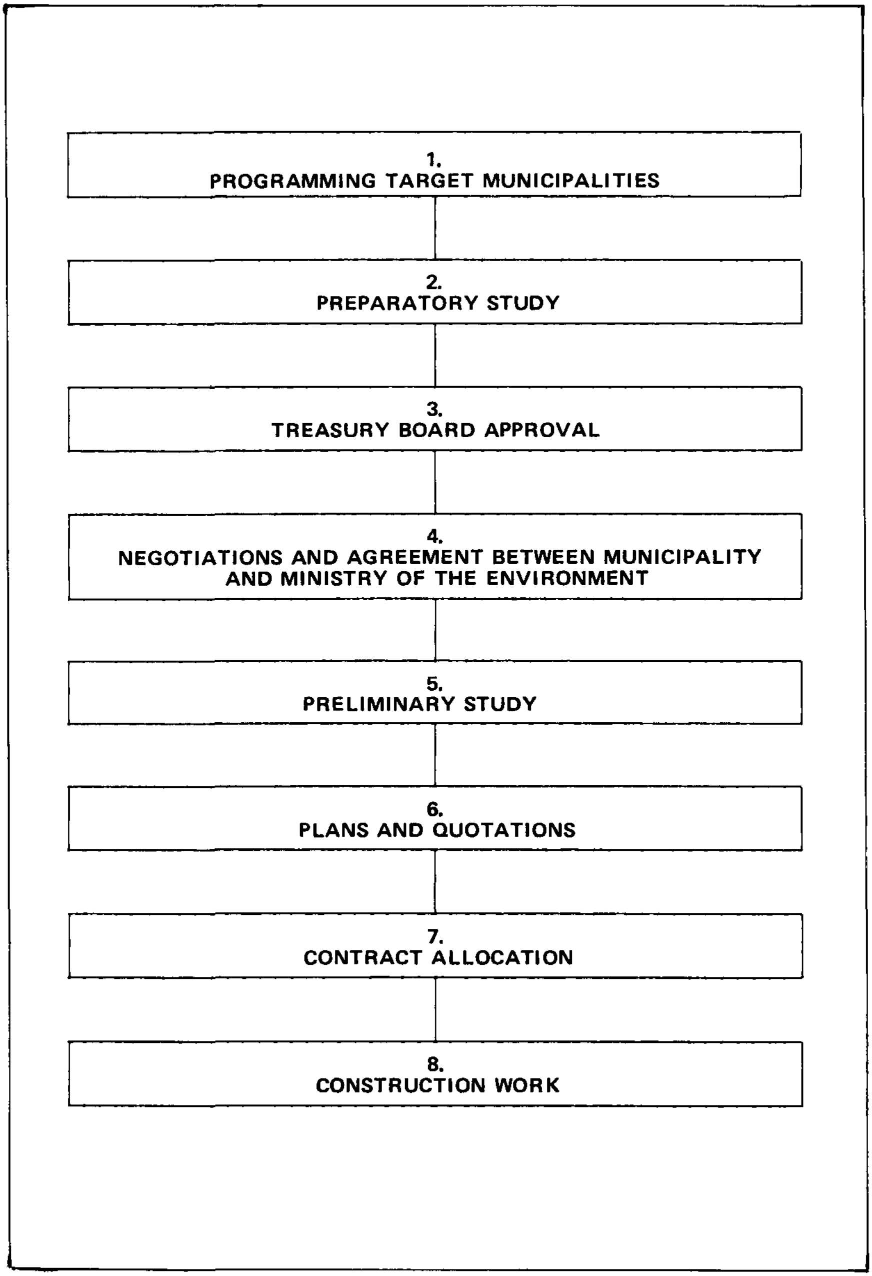

Figure 3. Administrative procedure used in the Québec municipal wastewater control program.

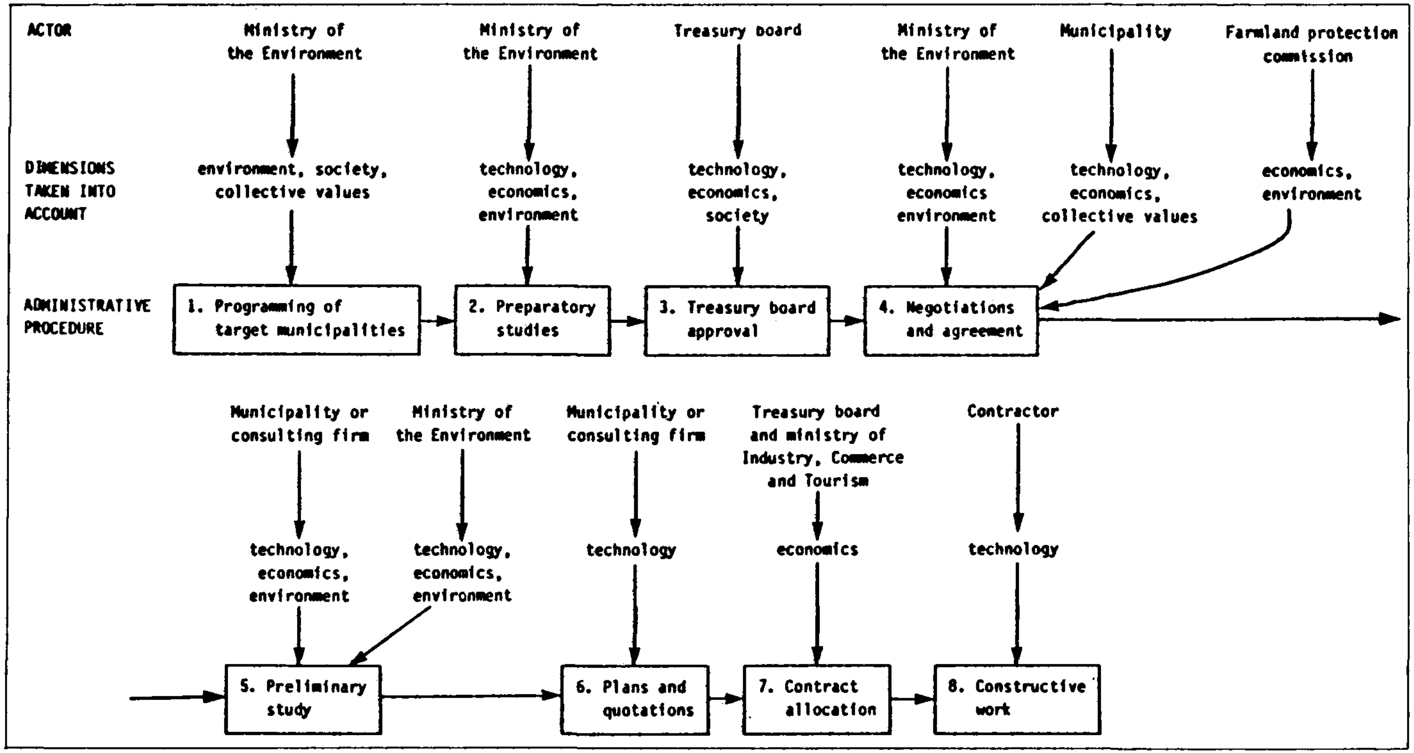

Figure 4. Schematic representation of the technology assessment procedure used in the Québec municipal wastewater pollution control program: the actors involved as well as the dimensions taken into account are identified for each step of the administrative procedure described in Figure 3.

project). Under the *Ministry of the Environment's* supervision, the municipality then makes a detailed preliminary study based on the ministry's previous recommendation: in most cases, consulting firms are hired for this task as well as the drawing up the plans and quotations. Construction contracts are awarded in conformity with the Québec government's purchasing policy, application of which is the joint responsibility of the *Treasury Board* and the *Québec Ministry of Industry, Commerce and Tourism.* The contractors may make very minor modifications in the plans during the construction phase.

We can now attempt to situate the procedure just described with respect to the types of technology assessment procedures presented in Table 3 by estimating the emphasis placed on each of the six dimensions:

1. *Technology.* Extensive: throughout the whole procedure, this is considered very important by every major participant involved.
2. *Economics.* Extensive: again, a pervasive dimension; the Québec government is specially insistent on the economic benefits generated within the province, as can be seen by its purchasing policy.
3. *The Environment.* Extensive: compliance with the effluent standards established by the ministry in its preparatory study influences the subsequent steps in the procedures.
4. *Society.* Limited: demographic data are the only elements explicitly pertaining to this dimension.
5. *The Individual.* Not taken into account.
6. *Collective Values.* Limited: the ministry of the Environment is responsive to popular demand for pollution control and municipal authorities are preoccupied by the electoral consequences of its voluntary commitment to the program.

By inserting the procedure into the classification (see Table 6), it is apparent that it is far removed from a comprehensive technology assessment: only three dimensions seem to merit extensive attention while the three others are scarcely taken into account. The procedure used by the *Québec Ministry of the Environment* is indeed more closely akin to environmental impact assessment.

CONCLUSION

Technological assessment methodologies are useful tools in evaluating a technology's impacts in many areas: technical, economic and financial, environmental, social, cultural, and political. They are thus an essential, even necessary, component in the design of global strategies in the private or public domains. In this article, we have seen that an informal technology assessment procedure can be reconstituted by analyzing the activities of the various parties involved in the municipal wastewater control program in Québec (Canada). Before any efforts are made to give it a more formal framework, it is essential to

Table 6. Situation of the Procedure Used in the Québec Municipal Wastewater Pollution Control Program With Respect to the Classification of Technology Assessments

	Dimensions Taken Into Account					
Assessment Type	*Technology*	*Economics*	*The Environment*	*Society*	*The Individual*	*Collective Values*
1. Technical performance	X[a]	X				
2. Cost-benefit analysis	X	X				
3. Market characterization	X	X			Lim.[b]	
4. Global economic cost	X	X		Lim.		
5. Environmental assessment	X	X	X		Lim.	Lim.
Technology selection in procedure used in the Québec wastewater pollution control program	X	X	X			Lim.
6. Technical-social cost-benefit analysis	X	X	X	X		
7. Multi-impact assessment	X	X	X	X	X	
8. *Comprehensive assessment*	X	X	X	X	X	X

[a] X denotes extensive emphasis.
[b] Lim. denotes limited emphasis.

understand its present scope and some of its deficiencies. This is treated in detail elsewhere [26], but let us mention here some aspects that merit particular attention:

1. the development of adequate operation and maintenance procedures for wastewater treatment systems;
2. the establishment of proper training programs for treatment systems personnel; and
3. the formulation of a research and development strategy in the wastewater treatment industry.

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