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Book Author(s): Werner Antweiler

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Chapter 6

Environmental Impact Assessment

Regulators need a set of procedures to review and approve proposed projects with respect to their environmental consequences. This process is formalized as environmental impact assessment (EIA) under US and Canadian law. Generally, EIA can be used to review the introduction of any new technology, project or program with respect to the full range of environmental consequences. Environmental consequences are typically explored in multiple dimensions: time (immediate versus long-term effects); space (local effects versus regional or global effects); and intent (direct anticipated versus indirect unanticipated effects).

EIA is a comprehensive and systematic process designed to identify, analyze, and evaluate the environmental effects of proposed projects. It is meant to integrate public concerns over environmental considerations into the decision-making process. It is thus a hugely important tool to help decision-makers achieve the goal of sustainable development. The term 'environment' in EIA is usually considered quite broadly and is meant to encompass both human effects (culture, health, community, financial) and biophysical or ecosystem effects (air, water, land, plants, animals).

In the United States, the enactment of the *National Environmental Policy Act* in 1970 provided the basis for an environmental assessment of any federal action. An environmental assessment leads either to a more detailed environmental impact statement or to a finding of no significant impact. Several US states have mirrored the federal procedures. For example, California requires an environmental impact report under its own *California Environmental Quality Act*.

EIA became entrenched in Canadian federal law in 1995 through the *Canadian Environmental Assessment Act* (CEAA). Thousands of EIAs are completed each year, ranging from local initiatives to large-scale resource development projects such as pipelines or hydroelectric dams. Almost all Canadian provinces have their own EIA systems. The federal body conducting EIAs is the Canadian Environmental Assessment Agency.

Environmental Impact Assessment (EIA) takes a prominent role when it comes to developing new projects. Noble (2006) provides a compact introduction into this topic with applications to Canada. Hanna (2009) is a more extensive edited volume with numerous contributions from leading experts on EIA in Canada. The book also includes detailed discussions of different provincial EIA procedures.

6.1 Objectives and process overview

EIA has both short-term and long-term objectives. Short-term objectives are procedural in nature and focus on the process of addressing environmental concerns in the design of a proposed development or project. A key objective of EIA is to identify or anticipate any adverse effects that could harm the environment, and propose solutions to avoid, minimize or offset these adverse effects. From a short-term perspective, EIA is an information tool for deciding on a proposed project.

EIA also involves long-term objectives, which can be viewed as outcome objectives rather than as process objectives. EIA is meant to promote development that is sustainable and facilitate participatory approaches to such development. Ultimately, EIA is about protecting human health and safety as well as the productivity and capacity of human and natural systems and their ecological functions.

These short-term and long-term objectives are all somewhat vague, and thus it is more useful to look at EIA as the set of procedures defined in law, which businesses need to comply with. From that perspective EIA can be broken up into individual steps of the review process:

1. **Project description:** description of proposed action sufficient for assessment, including project alternatives.
2. **Screening:** determination of whether the action is subject to EIA and determination of what level of assessment is required.
3. **Scoping:** delineation of key issues and assessment boundaries, including baseline conditions and scoping of alternatives.
4. **Impact prediction:** prediction of environmental impacts and determination of impact significance.
5. **Impact management:** identification of mitigation strategies and development of environmental management and protection plans.
6. **Review and decision:** technical and public review; recommendation on proceeding, and under which conditions.
7. **Implementation** of project and environmental management measures; compliance monitoring; monitoring of effectiveness of impact management measures and accuracy of impact predictions.

6.1.1 The EIA process in the United States

The legal framework for environmental impact assessment depends on the jurisdiction. Canada and the United States follow rather different procedures. The basis for EIA in the United States is the *National Environmental Policy Act* (NEPA), enacted in 1970. Canada's legislation followed fifteen years later and is more evolved as a result, having absorbed many of the critical lessons from the US experience.

The US NEPA mandates an environmental assessment for projects falling under federal jurisdiction, unless the projects are categorically excluded from review. An **environmental assessment** is an initial stage in which a federal agency prepares a preliminary analysis of potential impacts if the significance of the environmental impact is not yet known. This process can result in two outcomes. First, the process can end with a 'finding of no significant impact,' in which case the project can get implemented. Second, the process can end with the conclusion that an **environmental impact statement** (EIS) is needed.

In terms of the seven steps outlined above, environmental assessment covers the first two steps, 'project description' and 'screening.' The EIS covers the remaining steps. The environmental impact of a proposed project is rated as one of four distinct categories:

- Lack of objections (LO): no potential environmental impacts.
- Environmental concerns (EC): the review has found environmental impacts that require suitable mitigation measures.
- Environmental objections (EO): the review has found significant environmental impacts that need to be avoided and thus require substantial changes or consideration of a project alternative.
- Environmentally unsatisfactory (EU): the project must not proceed as proposed because (a) it would violate a national environmental standard; (b) it would have particularly severe, lasting, and widespread environmental consequences; or (c) it would threaten national environmental resources.

Environmental assessments can involve different federal agencies. The lead agency (in some cases multiple agencies) is the one that is directly involved in the project. The Environmental Protection Agency (EPA) has multiple roles in the process. As a cooperating agency it assists other federal agencies in preparing an EIS, and it has a mandate under the *Clean Air Act* to comment on the environmental impact of all major federal actions. If the EPA considers a proposed project to be environmentally unsatisfactory, the case is referred to the White House Council on Environmental Quality for arbitration.

Whenever an EIS is required, the process goes through several stages. A draft EIS is prepared by the lead agency. This version covers the entire range of environmental impacts and outlines possible alternatives. A comment period follows the circulation of the draft EIS. Feedback from the public is taken into consideration when the lead agency prepares the final EIS and suggests the proposed action. In some cases, a supplemental EIS can be required when deficiencies in the final EIS are discovered or the scope of the proposed project changes significantly. The process concludes with a **record of decision** by the lead agency. The only recourse against it is through suing the lead agency in federal court.

6.1.2 The EIA process in Canada

The Canadian legal framework for environmental impact assessment distinguishes different types. This recognizes the different levels of environmental impact from projects of different types: some have the potential for major impacts, while other projects may have minor impacts and can be subjected to a template-type screening.

The **Screening EIA** systematically documents the potential environmental effects of a proposed project, identifies mitigation measures, and determines the need to modify a project. If a project is found to have significant environmental impacts, it may be referred to a mediator or a review panel.

For routine projects, a **Class Screening EIA** may suffice. There are two variants of this type of EIA. Model class screenings are generic assessments in which certain design standards and mitigation measures are implemented. This also establishes a template for future projects of the same type. Replacement class screenings do not require location-specific or project-specific information, and are used for generic types of projects, such as special holiday events or activities in a national park.

A **Comprehensive Study EIA** is mandated for large-scale projects described under the *Comprehensive Study List Regulations* of Canada's EIAA. Such EIAs require additional screening steps that include: a detailed project description; specification of technical project alternatives; where applicable a discussion of the effect on renewable resources; and the need for follow-up to assess environmental impacts. EIAs of this type are triggered by meeting certain criteria during the screening phase, discussed below. Alternatively, a similarly comprehensive EIA can be formed as a **Review Panel EIA** appointed by the federal minister of the environment. The minister can exercise this discretionary privilege if the potential environmental effects of the proposed project are uncertain or are potentially very significant.

Panel reviews are common for major projects. Panels can be convened as joint panels with other regulatory bodies. It is common to convene a **joint review panel** for energy-related projects such as the construction of pipelines or power lines. Regulatory bodies that may participate include: the National Energy Board (NEB), Fisheries and Oceans Canada, as well as local regulatory entities. The NEB has federal jurisdiction for approving interprovincial and international oil and gas pipelines (exceeding 40 km in length), and international power lines. Pipelines or power lines that fall entirely within the territory of a province are subject only to provincial approval.

The 2012 revision of the *Canadian Environmental Assessment Act* mandates strict time limits on the review process. The Canadian Environmental Assessment Agency has 45 days to determine whether an assessment is needed, and it has 12 months (24 months for a review panel)

Box 6.1: Mackenzie Valley Gas Project EIA

In 2003 Imperial Oil, Shell Canada, ConocoPhillips, ExxonMobil Canada, and the Mackenzie Valley Aboriginal Pipeline Ltd Partnership submitted a preliminary information package describing the proposed Mackenzie Valley Gas Project and its related environmental and socio-economic issues.

The project involves the \$7 billion development of natural gas reserves in the Mackenzie River Delta in the Northwest Territories, as well as natural gas processing and the construction of a 1,220 km pipeline with a capacity of 34 million cubic metres per day for shipping the natural gas through the Mackenzie Valley to northern Alberta. Employment is expected to peak at 8,000 during construction and drop to 150 during operation of the pipeline. Up to 32 communities will be affected by the project.

The project is subject to an EIA under the CEAA, the *Mackenzie Valley Resource Management Act*, the *Western Arctic Claims Settlement Act*, as well as the National Energy Board. These bodies formed a joint review panel. Among other issues, the panel considered alternative locations for infrastructure sites, alternative routes for

the pipeline, and alternative methods of construction and reclamation.

The joint review panel made 176 recommendations to the minister of the environment in May 2010, 115 of them within federal jurisdiction. The minister accepted only 11 outright and asked 77 recommendations to be changed. The minister accepted only the intent of these 77 recommendations, but not the proposed implementation. The minister also rejected 27 recommendations, 20 of them because he deemed them to be outside the mandate (subject matter or geographic scope) of the review panel, and 7 because he disagreed with the panel's recommendations.

Federal cabinet approval of the project was granted in March 2011. The project's lead firm, Imperial Oil, had until the end of 2013 to make a decision on whether to proceed with the pipeline. In December 2013 the company announced that the project's original cost estimate of \$7 billion more than doubled to over \$16 billion. Because of the recent glut of natural gas from hydraulic fracturing (tracking), the Mackenzie Valley Gas Project remains uneconomic at this time.

to complete an assessment. The 2012 revision also allows the federal government to delegate the review process to a province if the federal government is satisfied that the province's review process is a sufficient substitute.

Box 6.1 illustrates the process and outcome of a joint review panel EIA for the Mackenzie Valley Gas Project. It illustrates the complexity of the decision-making process, as well as the political dimensions of that process.

6.2 Screening

In the United States, the screening process is essentially established through a federal agency's mandate and where a project is subject to federal permitting, licensing, or funding. In Canada, the process is more elaborate because specific screening criteria trigger the review process. These criteria differ federally and provincially, which may result in situations where a project requires only federal, only provincial, or both types of assessment. Where both federal and provincial EIAs are required, it is not certain that the outcome will be identical. For example, the Prosperity Gold-Copper Mine project by Taseko Mines Ltd. in the Chilcotin region of British Columbia was approved by the BC government in January 2010, but rejected by the federal government in November 2010.

The Canadian federal EIA only applies to projects, which includes activities in relation to physical works as well as other activities that are described in the *Inclusion List Regulations*. A project must then fulfill three additional criteria: (i) the project must not be specifically excluded from environmental assessment in the *Exclusion List Regulations*; (ii) the project must involve a federal authority; and (iii) there must be a trigger to initiate the assessment.

The inclusion list is relatively long. It contains any project carried out in a national park, a variety of oil and gas projects including pipelines, nuclear facilities, defence projects, transportation, waste management, fisheries, and projects on aboriginal and northern lands. The exclusion list is much shorter and exempts a variety of minor projects.

Comprehensive Study List Regulations identify projects likely to cause significant adverse effects or significant public concern (e.g., activities in a national park, nuclear facilities, mining and mineral processing operations) for which an EIA is required, and are subject to categorization according to project thresholds. A few examples of screening thresholds illustrate the concept. A Comprehensive Study EIA is required for the proposed construction, decommissioning, or abandonment of: (i) a fossil fuel fired electrical generation station with a capacity of 200 MW or more; (ii) a heavy oil or oil sands processing facility with an oil production capacity of 10,000 m³/day; (iii) a metal mine, other than a gold mine, with an ore production of 3,000 tonnes/day or more. A Comprehensive Study EIA is also required for the construction of: (iv) an electrical transmission line with a voltage of 345 kV or more that is 74 km or more in length on a new right of way; and (v) the proposed construction of a railway line more than 32 km in length on a new right of way. These examples illustrate the regulator's need to delineate major and minor projects. These thresholds are often rules of thumb and may in some cases trigger opportunistic behaviour to avoid a particular type of EIA in favour of a less comprehensive examination.

6.3 Scoping

Scoping determines the important issues and parameters that should be addressed in an environmental assessment. Scoping also establishes the boundaries of the assessment, and focuses the assessment on these relevant issues and concerns. It defines those components of the biophysical and human environment that may be affected by the project and for which there is public concern. Scoping may be either open or closed. In the case of closed scoping, the scope of the EIA is predetermined by law. In the case of open scoping, issues and boundaries are identified through stakeholder consultation.

Scoping involves a number of separate steps. The starting point is the detailed project description, and based on this the development of **project alternatives**. Alternatives serve an important function in the assessment process. They provide the assessment panel with an opportunity to consider variations that may better satisfy environmental concerns. Even though the applying company may favour the main proposal on cost grounds, sometimes trade-offs need to be made. If the applying firm proposes only a single alternative, the assessment panel is forced to make an up-or-down decision. However, with reasonable alternatives it is possible to salvage an application. For example, when proposing a route for a new pipeline, it may be necessary to consider alternative routing as unforeseen environmental concerns may come to light that make the proposed route less attractive. There are three dimensions of project alternatives:

- alternative projects that achieve the intended project purpose in different functional ways (for example, an above-ground skytrain system versus a below-ground subway system)
- alternative locations (for plants or mines) or routing (for transmission and transportation systems);
- alternative designs (technological implementation).

These three dimensions of project alternatives rank from more challenging to less challenging. Alternative projects often involve hugely different costs and thus the set of alternatives is often very constrained. Alternative locations may also not be readily available because of: (i) fixed location (e.g., mines); (ii) topographical constraints (e.g., pipeline routes); and (iii) land-use constraints (e.g., proximity to settlements, or ownership). Alternative designs are often the most readily available as the variations can be minor. For example, when building a power plant, different pollution abatement devices may accomplish different emission reduction targets.

The next steps in the scoping process involve identifying the **assessment boundaries** for the impact areas that will be considered, and the

environmental baseline against which alternatives can be compared. Boundaries are established in three dimensions:

- **media:** the parts of the ecosystem (e.g., air, water, wildlife) that need to be included in the assessment;
- **space:** the jurisdictions that need to be considered in the assessment, which in turn depends on the spatial extent of the possible environmental impacts; and
- **time:** the time horizon for the environmental assessment, for physical projects typically from construction to decommissioning plus five years.

The last step in the assessment process involves identifying potential impacts and environmental issues along these dimensions. This process results in a list of **impact indicators**. These indicators are arranged in an **impact matrix** where each project action can be quantified or ranked.

6.4 Impact prediction

Scoping puts boundaries around which environmental impacts will be assessed, and which alternatives will be considered. Quantifying all the possible environmental impacts is perhaps the most difficult step—this is the task for **impact prediction**. Often the main challenge is finding solid and reliable data.

For predicting impacts, direct measurement is always preferable but in many instances not feasible. Such direct measurements typically come from similar projects that already exist elsewhere, and the challenge is adapting these data to local circumstances and conditions. When measurement is not possible, impact prediction through a scientific model is the next-best choice. Such a model can be calibrated to existing observables, and then simulation exercises can be performed to predict changes to the model. The drawbacks of simulation models are that the numerical calibration may be coarse or that the model is driven by particular assumptions that are difficult to verify empirically. Nevertheless, scientific models of one kind or another remain the main tool for impact prediction.

Where direct measurement or simulation is not possible, qualitative scoring is used. A commonly used technique for qualitative impact assessment is the **Delphi method**, in which experts are questioned in two or more rounds, often involving questionnaires. After each round of questioning, the experts are presented with a summary of the other experts' assessments and their reasoning for arriving at their conclusions. This process is meant to facilitate an (anonymized) dialogue among the experts that will help them converge to a consensus in multiple rounds of questioning.

What exactly is meant by the term *impact*? There are two elements to assessing impact: quantifying a measurable effect on the environment ecosystem, or health; and assessing the relative importance of the measured effect. Assessing relative importance involves putting weights on different impact categories, a process which almost always involves expert panels. Two important methods for obtaining weights will be discussed below: fixed-point scoring and analytic hierarchy process.

Impacts can be direct or indirect. A proposed project always has a direct impact. For example, the proposed construction of a hydroelectric dam may cause a decrease in the growth rate of fish. Many projects also have indirect (second-order) effects. In the example of the proposed hydro dam, the decline in fish growth may diminish opportunities for downstream recreational fishing, or threaten other species that depend on a supply of fish. A dam may cut off salmon from their spawning habitat (a direct effect), and the lack of salmon may adversely effect upstream bear populations (an indirect effect).

Table 6.1 Classification System for Environmental Impacts

Type of Impact	Temporal Dimension	Impact Magnitude
adverse incremental additive synergistic antagonistic	duration continuity immediacy frequency regularity	size degree concentration
Spatial Extent	Reversibility	Impact Probability
on-site off-site	reversible irreversible	likelihood risk uncertainty

Table 6.1 describes the multitude of impact categories and impact dimensions that can be considered. The type of impact describes its positive or negative, additive or multiplicative effect. In most instances, a proposed project will result in **adverse** effects that can be described as level changes in environmental conditions directly attributable to the proposed project. Such adverse effects can be magnified by becoming **incremental**, where the changes are not in one-off level changes (a jump from one level to another) but in changes to growth rates (where the level continues changing indefinitely). When a single effect is present, it may occur in multiple instances. Such effects can be **additive**. Even when the consequences of separate or related actions are minor individually, their overall effect may be major. For example, the exhaust from one car has relatively minor environmental effects, but thousands of cars on a city’s road may have a major effect.

It is also possible to find situations where different effects interact in a positive or negative way. One speaks of **synergistic** effects when interactions between different effects result in a total effect that is larger than the sum of the individual effects. For example, a paper mill effluent may (i) change water temperatures, and/or (ii) lower dissolved oxygen content in water. Effects (i) and (ii) may be tolerable to fish separately, but not when they are combined. It is also possible that interactions result in one adverse effect offsetting another adverse effect; these are considered **antagonistic** effects. For example, a water body may receive effluents containing (i) chlorine and/or (ii) phosphates. Each effect alone leads to eutrophication, but when (i) and (ii) are combined the eutrophication effect cancels out partially.

All environmental impacts have a time dimension. The temporal dimension can be characterized in five categories. First is the **duration** of the impact. Duration can be short term and temporary (such as during a construction project) or long term and permanent (such as riverbank erosion or downstream loss of arable land from a hydro dam). Second is the **continuity** of the impact. Some effects may be continuous (such as the energy field associated with a transmission line), while others are discontinuous (such as blasting noise at a mine). Third is the **immediacy** of the impact, which is closely related to the distinction between flow pollutants and stock pollutants. For example, odour from livestock has an immediate impact, while toxics slowly accumulating in groundwater have a delayed impact. Fourth is the **frequency** of the impact. The impact of a proposed new airport runway or new railway line may differ dramatically depending on the number of planes taking off and landing, or trains passing through. Fifth and last is the **regularity** of the impact, which describes the temporal predictability of the disturbance. For the effect on a nearby population, it may matter significantly if occurrences of adverse effects are regular (predictable) or irregular (unpredictable). A new railway line may have predictable effects as the trains run on a schedule, while the blasting noise from a highway construction project may occur at unpredictable times during the day.

The spatial extent of impacts depends crucially on the environmental medium that is impacted. Noise does not travel far under normal circumstances. The impact of a high-voltage power line is in the order of tens of metres. The impact of a proposed new airport runway can be localized in terms of a few kilometres. The impact of sulfur dioxide emissions from a new coal power plant is measured in tens or even hundreds of kilometres. The impact of carbon dioxide emissions is global. Defining the scope in spatial terms not only touches on environmental concerns but also touches on concerns about jurisdiction. For example, should an environmental impact assessment in Ontario consider adverse effects in the neighbouring province of Quebec? Should Ontario consider adverse effects in New York State? Will jurisdictions weight

impact on their own territory the same as impacts on neighbouring jurisdictions?

A useful tool for capturing the spatial extent of environmental impacts is a **dispersion model**, a mathematical model that predicts pollution concentrations as a function of distance from the source, along with a variety of attenuating factors. For air pollution, such attenuating factors can be the height and diameter of a plant's stack, the stack gas exit velocity, temperature of the exiting gas and surrounding atmosphere, as well as wind speed and direction. For water pollution, a river's width, depth, speed, and curvature may all affect how fast pollution concentrations will diminish with distance.

The severity of environmental impacts often depends on their reversibility or irreversibility. A reversible impact allows the environment to return to its pre-disturbed condition. For example, a surface mining operation may restore a disturbed forest to its original condition once the mining activity has ceased. Other effects may be irreversible. Razing the forest for the mining operation may also lead to the extinction of, say, a bird species. Many impacts are partially reversible. In that case it is not feasible to restore the environment to its prior *pristine* state but to a posterior *acceptable* state. For example, in Germany's Rhineland, many townships were moved and forests removed to facilitate large open-pit soft-coal mining, but after the mines were decommissioned the affected areas were restored to lakes and parkland, and in part resettled. Nevertheless, the success of remediation depends on whether it is possible to reactivate the original ecological functions. For example, it is possible to revegetate disturbed soil rather than restore it to its original function (such as a boreal wetland). Remediation practices may therefore lead to the **reclamation** of an industrial site rather than **restoration** of the original ecosystem. Reclamation is easier than restoration.

Environmental impacts are not always certain. Some impacts arise only with a certain likelihood or probability. Impact assessment may thus turn into **risk assessment**. If it is possible to quantify the uncertainty by attaching probabilities to different outcomes, the potential damage can be assessed by multiplying corresponding effects and their probabilities, and summing across the different impact groups or potential outcomes. For example, elderly people and young children may be more vulnerable to exposure to air toxics than are other age groups. Uncertainty about impacts on these different groups can be averaged using statistical techniques. Another example is the likelihood of oil spills of different magnitude. Historical data suggest a certain probability distribution, with small spills more frequent than large spills. Statistical averaging provides a useful tool for tackling uncertainty.

The notion of **uncertainty** can mean two different things. Some impacts may be uncertain but their likelihood of occurrence, or the likelihood of different levels of severity, can be quantified. In this case, risk

analysis can be carried out by capturing the environmental impact as the expected average (perhaps along with a statistical range or standard deviation). It is perhaps useful to describe this concept as *statistical uncertainty* or *risk*. The other type of uncertainty is not measurable and cannot be conquered using statistical techniques; it is sometimes referred to as *true uncertainty*. In environmental impact assessments, unmeasurable types of uncertainty surface in the form of speculative impacts. Lack of scientific research on a particular impact, or scientific research that is inconclusive or lacking in robustness, may lead to a particular type of impact being excluded from an assessment. For example, there exists a degree of uncertainty about the potential effects of genetically modified organisms (GMOs) because such GMOs are relatively novel. Their environmental impact remains a subject of intense study, but with results not yet fully conclusive (despite claims to the contrary from both proponents and opponents alike).

6.4.1 Fixed-point scoring

There are several methods available to assign weights to different impact categories. The method of fixed-point scoring involves defining weights w_i for each impact category i such that $\sum_i w_i = 1$. This always involves trade-offs. Increasing the weight of one impact category implies reducing the weight of all other impact categories.

Weights are obtained through polling panels of experts and decision-makers, for example through the Delphi method described above. Assigning weights is always a subjective process, and therefore using a technique that leads to some form of consensus through multi-round dialogue is perhaps more useful than simply conducting a survey and averaging results.

Table 6.2 provides an example of the fixed-point scoring technique. The rows identify different impact categories such as air quality and water quality. The columns identify a variety of activities related to the construction of a new highway, such as blasting and dredging. Impacts are rated on a -5 to +5 scale.

The total impact for each impact category is obtained by multiplying the impact scores by the pre-defined weights. For example, in the first row (air quality), the sum of scores (-3) is multiplied by the weight (0.26) to yield -0.78. Scores are then added up to a grand total. This grand total can then be compared across project alternatives.

Table 6.2 Example of a Weighted Magnitude Matrix

	weight	blasting	side cleaning	dredging	road construction	waste disposal	equipment transport	Total impact
air quality	0.26	-1			-1	-1		-0.78
water quantity	0.10	-2	-3	-3				-0.80
water quality	0.22	-2	-4	-2				-1.76
noise	0.04	-2		-1	-2		-2	-0.28
habitat	0.08		-5		-3			-0.64
wildlife	0.08	-2	-4		-2			-0.64
human health	0.22	-2			+3	-3		-0.44

Impact scale: + = positive ; - = negative; (blank) = none; 1 = negligible; 2 = minor; 3 = moderate; 4 = major (long-term); 5 = severe (permanent)

6.4.2 *The analytic hierarchy process*

Multi-criteria decision analysis is a very subjective process. One way to reduce the complexity of the problem is to take the catalog of environmental assessment criteria and sort them into a hierarchy of assessment areas, groups, and subgroups as necessary. For each group at each level one can conduct pairwise comparisons of the relative importance of the assessment criteria in this area. This procedure of organizing the assessment criteria in a tree-like structure is known as the **analytic hierarchy process (AHP)**, developed by Saaty (1980).

Pairwise comparisons are rated on a scale from 1 to 9, where 1 indicates equal importance of the two factors and 9 indicates extremely more important. The intermediate values 2-8 indicate increasing importance; see the left panel in table 6.3. These pairwise comparisons are collected in a decision matrix **A** where element a_{ij} indicates the intensity of importance of option i over option j . For example, if option i is absolutely more important than option j , then $a_{ij} = 9$ and $a_{ji} = 1/9$. With n options, the elements of the $n \times n$ decision matrix **A** are reciprocal so that $a_{ji} = 1/a_{ij}$. By construction, $a_{ii} = 1$. The top right panel in table 6.3 provides a numerical illustration for three environmental criteria: air quality, water quality, and noise. In this environmental assessment, the experts judged that air quality is weakly more important than water quality (score 3) and strongly more important than noise (score 7). Water quality was considered slightly more important than noise (score 2).

To calculate the weights w_i , we obtain the **principal eigenvector** of the decision matrix A . With linear algebra software it is easy to calculate the eigenvalues λ and corresponding eigenvectors $\mathbf{v}$ that satisfy $\mathbf{A}\mathbf{v} = \lambda\mathbf{v}$. The eigenvector that corresponds to the largest eigenvalue $\lambda^{\max}$ is the principal eigenvector. Because the A matrix is positive, the elements of the principal eigenvector are also positive. We then normalize the elements v_i of the principal eigenvector so that the weights $w_i \equiv v_i / \sum_j v_j$ sum to 1. Column w in table 6.3 reports the results of this procedure. Air quality is most important (weight 0.68), followed by water quality (0.22) and noise (0.10).

Table 6.3 The Analytic Hierarchy Process

Intensity Score of Pairwise Comparisons		Numerical Example				
Relative Importance		i	1	2	3	w
1	equal	1	1	3	7	0.682
2	equal to moderate	2	1/3	1	2	0.216
3	moderate	3	1/7	1/2	1	0.103
4	moderate to strong					
5	strong					
6	strong to very strong					
7	very strong					
8	very strong to extreme					
9	extreme					

Random Consistency Index (RCI)						
n	3	4	5	6	7	8
RCI(n)	0.4913	0.8264	1.0363	1.1699	1.2576	1.3197
n	9	10	11	12	13	14
RCI(n)	1.3639	1.3978	1.4250	1.4468	1.4650	1.4802
n	15	16	17	18	19	20
RCI(n)	1.4931	1.5039	1.5141	1.5224	1.5298	1.5368

Pairwise comparisons do not have to be consistent with each other. Consistency would require that for any $i \neq j \neq k$, it should hold that $a_{ij}a_{jk} = a_{ik}$. The experts may not always rank choices consistently, and fortunately the principal eigenvector method is relatively robust to such judgment errors. One can judge the consistency error by the ratio of the consistency index $CI \equiv (\lambda^{\max} - n)/(n - 1)$ and a random consistency index (RCI), shown in the bottom right panel of table 6.3 for matrices of size 3–20.¹ If the ratio of CI to RCI exceeds 0.1, the consistency problem is considered unacceptable and the resulting weights may not be reliable. In our example, the CI is 0.0013 and the corresponding RCI is 0.4913, so the CI/RCI ratio is well below 0.1.

The last step in applying the AHP framework is to consider the tree-like hierarchical structure of the assessment criteria. Every branch has a set of criteria whose weights add up to 1. It is now straight forward to successively aggregate criteria from the branches down to the root

¹ Own calculations based on one million random matrices.

using these weights. To keep everything in comparable units of measurement, it is necessary to score each assessment criterion on the same scale (e.g., a 0–100 scale or a –10 to +10 scale).

6.5 Impact management

When particular environmental impacts have been identified, EIA can help develop strategies to tackle these impacts in order to reduce their severity. Impact management tries to identify ex-ante (before implementation) and ex-post (after implementation) strategies that:

1. **avoid** environmental impacts, perhaps by considering project alternatives;
2. **mitigate** environmental impacts, either by considering alternative ways to implement a project, or by deploying technologies that contain or reduce the impact;
3. **remedy** environmental impacts after they have occurred; and
4. **compensate** victims of environmental impacts.

Strategies are considered in this priority order. The last of these options, compensation, is therefore considered only when all else fails. Compensation can involve monetary benefits when individuals are involved. When plant and wildlife habitat is concerned, compensation may also involve the creation of an offsetting habitat in a different location so that there is no net loss of habitat.

6.5.1 *Avoidance and mitigation*

Avoiding environmental impact is obviously the first and best option wherever feasible. This can involve using substituting substances with less toxic or non-toxic substances. For construction activities, traffic congestion can be avoided by scheduling trucks to arrive outside rush hour.

Mitigation is designed to minimize environmental impact where some impact is unavoidable. For example, building a new road will have some adverse effects during the construction phase as well as the operation phase. During the construction phase, dust build-up can be minimized by watering gravel surfaces frequently. Noise disruptions can be minimized by limiting construction work to certain hours of the day. During the operation phase, wildlife habitat fragmentation can be reduced by building wildlife overpasses or underpasses.

To provide another example, logging operations can erode the forest soil and lead to excessive water run-off. While soil erosion is not avoidable completely, its magnitude can be controlled through the use of **buffer zones** of undisturbed vegetation.

6.5.2 Remediation techniques

There exists a plethora of remediation techniques that can be deployed to clean up a spill or leak, or restore a contaminated site. The first set of options aims to contain the contamination. This can involve the use of: walls, liners, or other means to contain a contaminant in a particular area; the installation of **treatment walls** in the ground to capture contaminants in groundwater flowing through these filters; or using other methods of **stabilization** or **encapsulation** that capture or transform contaminants into stable solids that will render them immobile or inert.

The next set of options involves *in situ* treatment. A variety of physical, chemical, or biological treatments can help reduce the level of contamination, depending on the type of contamination. With **air sparging**, air is injected into contaminated soil, and the air bubbles that rise to the surface will carry trapped and dissolved contaminants with them. Air sparging can also be used to inject air into contaminated groundwater to enhance biodegradation or volatilize contaminants. Contaminant vapours can also be collected through vacuum extraction wells, a procedure known as **soil vapour extraction**. Air sparging has been found to be effective in reducing concentrations of volatile organic compounds found in petroleum products at underground storage tank sites. It works best for lighter gasoline constituents and less well for diesel fuel or kerosene. At about \$20–\$50 per tonne of saturated soil, air sparging is often less costly than above-ground treatment options.

With **soil washing**, a contaminated area is flooded with water or a solution that moves contaminants to a location where they can be collected and treated. Contaminated soil can also be treated with **thermal desorption**, whereby the soil is heated to vaporize contaminants. Chemical **dehalogenation** can convert halogen contaminants into less toxic substances through furthering chemical reactions that bind or break down the halogens. Halogens are a class of chemical elements that includes chlorine, bromine, iodine, and fluorine. The process involves removing the soil, treating it in a dehalogenation reactor, and post-treating it in a separator/washer. The cleaned soil can be returned to the original site. Chemical dehalogenation is frequently used to separate and remove chlorine from PCBs and dioxins contained in polluted soil, sludge, or sediment.

With **bioremediation**, organic contaminants can be rendered harmless through the injection of a mixture of bacteria and nutrients into the soil. Bioremediation can be performed *in situ* or *ex situ*. Bioremediation can sometimes be used in areas that are inaccessible without (expensive) excavation. Bioremediation can also be used effectively for hydrocarbon (e.g., petrol) spills. A related method, **phytoremediation**, involves planting vegetation that takes up contaminants from the soil. This process concentrates the contaminants, and the polluted vegeta-

tion can eventually get collected and disposed of suitably. Phytoremediation is often used when heavy metals such as arsenic, cadmium, or lead are key contaminants. Plants that work well as accumulators are sunflower (for arsenic), willow (for cadmium), and ragweed (for lead).

Another set of options involves *ex situ* treatment. In turn, this involves transporting the contaminated material, water, or soil to a site that is better suited to store or process these substances. This can involve pumping contaminated groundwater to the surface for treatment and injecting it back into the water table after treatment, or excavation of contaminated soil and removal to an off-site landfill for disposal (also known as 'dig-and-dump'). Last on the list is natural attenuation, which relies on natural biological or physical processes to decrease the level of contamination over time.

Which remediation options work best at a given site are a combination of the contamination substance, the accessibility of the site, and the severity of the contamination. Cost considerations give *in situ* treatment an advantage over *ex situ* treatment.

6.6 Summary

Environmental impact assessment (EIA) is a comprehensive and systematic process to identify, analyze, predict, and evaluate the environmental effects of proposed projects. The EIA process allows for the participation of the public and for the consideration of public concerns. EIA is a decision-making tool that may result in approval or rejection of a proposed project, as well as recommendation of modifications and improvements to a proposal. In the United States, EIAs are mandated under the 1970 NEPA statute and are organized into a two-step framework: an environmental assessment and an environmental impact statement. In Canada, EIAs are mandated by federal and provincial law, and may overlap in many instances. EIA is triggered by a screening process, and the size and scope of a project determine how the EIA process is conducted. Larger projects typically require a panel review, while routine projects may be handled by a template-type class screening review. EIAs are conducted through public consultations and expert reviews. Key steps involve 'scoping' (determining the spatial, temporal, and media-specific boundaries of the analysis), 'impact prediction' (scoring the environmental impact of project activities along different impact categories, and weighting these impact categories), and 'impact management' (avoiding, mitigating, or remedying adverse effects). The process results in the recommendation of improvements to the project proposal, the consideration of project alternatives, or the suggestion of particular impact management strategies. Recommendations by EIA panels are subject to discretionary and selective ministerial approval.

6.7 Study questions and exercises

1. Describe the environmental impact assessment (EIA) procedure and explain the distinct steps that lead towards project approval.
2. What are major types of EIA?
3. What is 'scoping,' and under which conditions can it become controversial?
4. What are the steps for 'impact prediction'?
5. Consider the classification system for environmental impacts. What are the major *categories* of environmental impacts, and in particular, what are specific *types* of environmental impacts?
6. How can *fixed-point scoring* and the *analytic hierarchy process* be used to develop weights for different impact categories?
7. Are the recommendations from an EIA panel binding, or can the Canadian minister of the environment pick and choose among recommendations?
8. If both provincial and federal EIAs are conducted in parallel, is it sufficient to get approval from one regulator or is it necessary to get approval from both?
9. Compare the US and Canadian approaches to EIA. Discuss the similarities and differences. Which approach involves more political discretion?

Exercises

1. Develop a template for an EIA for a gasoline station, with a particular focus on scoping and impact prediction. Separate the environmental issues during the operation of the gas station from the environmental issues after its closure. What are the legacy risks? What remediation techniques can be used for cleaning up an abandoned gas station site?
2. Obtain the report of a major EIA that was completed about a decade ago; such reports are publicly available in Canada and the United States. Summarize the crucial elements of the EIA and determine which recommendations were in fact implemented. Analyze the efficacy of these measures ex-post.