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Framework to Assess Environmental Science and Technology Research Capacities in Canada

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Framework to Assess Environmental Science and Technology Research Capacities in Canada

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THE IMPACT GROUP

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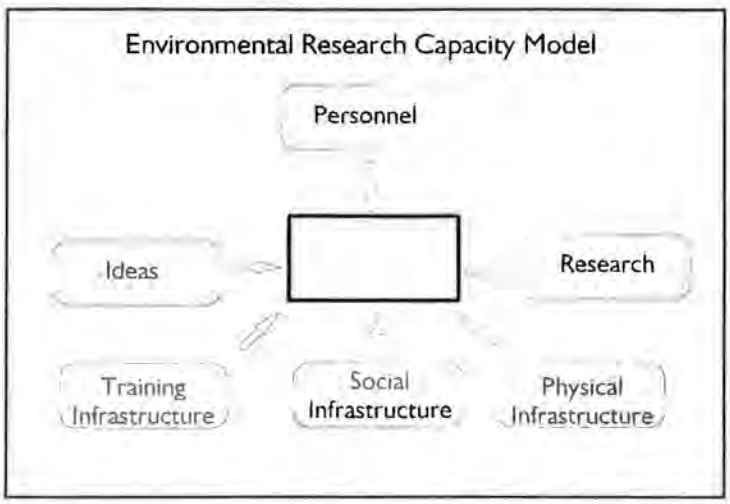
1.0 INTRODUCTION

This report was commissioned by Environment Canada, as part of the work of the Canadian Environmental Sciences Network (CESN). CESN is intended to be a mechanism to increase the authority of environmental science and investment through a number of activities, including the development of a national environmental research agenda and investment stratety, in partnership with other organizations. The CESN steering committee believes that it would be helpful to develop a benchmark understanding of national environmental research **capacities**, before initiating any major new research initiatives. In preparation for an in-depth study that might provide this kind of information, CESN decided to support the development of an "environmental research capacities framework" - a system for describing and analyzing national environmental research capabilities.

2.0 AN ENVIRONMENTAL RESEARCH CAPACITY MODEL

What factors should a country take into account in assessing its environmental research capacity? In this section we propose a model for assessing research capacity (see right). The model includes 6 elements that together describe capacity from a research perspective.



2.1 Research Personnel

The first capacity "ingredient" is **personnel**, specifically research personnel. The number of full- and part-time researchers actively engaged in environmental research is the core measure of a nation's environmental research capacity. Environmental research personnel can be found in universities (professors, graduate students), industry, government and non-profit organizations. At any point in time the number of qualified personnel available to engage in environmental research sets an upper limit on the country's capacity for research.

Research capacity changes over time, and in the medium term - say 2-5 years - there is a considerable amount of elasticity in the pool of qualified research personnel - in particular university-based researchers. For one thing, researchers' interests can change over time, and a university researcher working one year on a non-environmental project might well focus another year on a project with environmental consequences, and vice versa[1]. Nevertheless, in principle, it should be possible to measure the size of the environmental research pool at different points in time.

The best way, because relevant "transaction" data are available[2], is to identify those individuals (or teams, networks, etc.) who have received grants, contracts or contributions to undertake environmental research. However, this is not a perfect approach; for example, it does not capture internal funds that might be available for environmental research. Also, databases usually indicate the name of the Principal Investigator who has received the grant, but do not indicate the number of individuals (e.g. students, postdoc, technicians) working with the PI. Nor do they provide information about the time the PI or others spend on research, say, in person-years. So, while the data may show that *n* PIs have received *x* contracts valued at $*y* it is still hard to estimate the total number of individuals working on the projects, or the amount of time they are devoting to research. Of course, it is possible to develop some rules-of-thumb that would permit estimates to be made - for example, one could develop an estimate of the number of graduate students working on a project per $100,000 of research activity. But this would involve a very different level of analysis and could introduce further complications (such as determining differences in researchers/$100,000 for different fields of environmental research in (say) the social sciences, natural sciences or life sciences.

In practice, some data needed to estimate personnel levels (e.g. # of grants, $ value, #PIs) are readily available from some sources, whereas other data will be more difficult to find (e.g. # of researchers). (See Chapter X for more discussion of data sources.) Still, data such as these are a cornerstone of capacity estimations.

2.2 Research Activity

A second indicator of research capacity is **research activity**. Research activity can be measured in a number of ways. First, is the volume of research being undertaken, in particular:

1. The number of active individual research projects (in universities, industry, government, etc.)

2. The number of research programs - collections of research projects.

[1]Incentives for research, such as a new grant program, can influence the size of the research pool. So can shifting fashions in research.

[2]For example, through the Granting Agencies, federal SBDAs, and StatCan industry surveys.

3. The amount of money being spent on research, as indicated by total dollars spent and average spending per project.

Although research activity is being proposed as a measure of research capacity, we offer several words of caution about this. It is important to keep in mind that capacity and activity are strictly speaking not the same thing. Capacity refers to the potential (of the research system) to conduct environmental research, whereas activity is an indicator of the output of the system - the work that results from the existing capacity over a predetermined span of time. Whereas the capacity of the system - its full potential for producing environmental research - might be described as 100%, the output of the system at any one time might only be (say) 80%, because not all resources are being used or not being used productively.

To compensate for this, in principle it would be desirable to develop a "capacity-utilization" measure, such as is used to describe manufacturing capacity[3]. However, this would prove difficult in practice. For one thing, as described earlier, the research system is somewhat elastic. Whereas in the manufacturing system, output and installed capacity are closely linked - a fixed amount of installed capacity will yield a fixed amount of manufactured output - in the research system, capacity is not as strongly "fixed" as in manufacturing, because incremental resources can often be harnessed to conduct additional research. For example, if a new environmental grant program were announced, it would likely attract the participation of new researchers who were not conducting environmental research, but whose skills and facilities could be adapted in that direction. Thus, system capacity would expand as new researchers adapted their existing skills (and infrastructure) to environmental research. Nevertheless, with this caution in mind, research activity and in particular trends in research activity do provide a useful indicator of capacity, albeit a surrogate measure[4].

One difficulty with actually measuring research activity is that there is no comprehensive listing of (environmental) organizations that provide research grants, contracts or contributions. So, in practice, one would need to comb the records of many different organizations, from the Granting Councils to the Ontario Challenge Fund, Agriculture Canada, Climate Change Action Fund, to the World Wildlife Fund and so forth. Practically speaking, the vast majority of research funding will come from a small set of organizations that include the Granting Agencies and Environment Canada. However, it is hard to know what proportion of activity is being supported by smaller funders and non-obvious organizations. In total, these activities could be significant. An additional problem is that it would be hard to track foreign funding of environmental research in Canadian organizations. Though this number is undoubtedly small in comparison with domestic funding, in the ideal world it would be useful to have a handle on foreign funding.

[3]For example, economists speak in terms of manufacturing performing at *n*% of capacity.

[4]In practise, research activity may also be one of the easier capacities to measure.

Compounding these difficulties is the fact that in many organizations, there is no distinct information on the "environmental" projects they fund. For example, it is doubtful that Agriculture and Agri-Food Canada keeps track separately of the environmental projects it funds, as distinct from non-environmental projects. Another challenge to be overcome is that some organizations will consider their records to be confidential and may balk at releasing information.

So, there are considerable difficulties in translating the general technique - counting environmental research grants, contracts and contributions - into a practical measure of national research capacity. A compromise solution might be to focus on the records of a limited number of major research performers.

2.3 Physical Infrastructure

Environmental research capacity can also be described in terms of **physical infrastructure** - the capital stock of research facilities and equipment. This indicator is akin to measures of installed capacity of manufacturing plant and equipment. Infrastructure capacity measures would focus on a number of quantifiable indicators. Assuming that appropriate definitions could be established[5], one would want to measure:

- The number of environmental research laboratories and research organizations[6] (e.g. Environment Canada's Environmental Technology Centre);
- The number of major environmental research facilities (e.g. solar energy test facility) and major pieces of equipment (e.g. equipment valued at over $500,000)[7];
- Replacement cost and depreciated value of physical infrastructure;
- Annual capital expenditures on environmental research infrastructure (e.g. the new Environment Canada Wildlife Research Centre); and,
- Repair and maintenance expenditures.

As in the case of research activity, measuring trends in physical infrastructure (stocks, investment, depreciation, etc.) can yield a useful indicator of a country's research capacity. If, for

[5]For example, the definition of an environmental research lab might be a lab that conducts 50% or more of its research for environmental purposes.

[6]This would be defined as organizations or laboratories where 50% or more of the research is of an environmental nature.

[7]"Entry-level" infrastructure costs vary among research fields. For example, climate modelling requires supercomputers valued in the $ millions, whereas toxicology research may require chromatographs valued in the tens of thousands of dollars.

example, it were determined that capital stock is declining (or otherwise), that would be an important signal as to the health of environmental research capacity.

The difficulty with this approach is that few organizations - especially the major research performers such as government departments and universities - maintain capital balance sheets for their research infrastructure assets. (The concept of capital depreciation is alien to public sector organizations; most simply write off the cost of capital in the year in which the expenditures are incurred.) This approach would work best in industry, which does maintain good capital accounting records; however, industry's environmental research infrastructure is probably the smallest portion of the national total. As there are no useful accounting records for government or universities, it would be necessary to develop a series of comprehensive annual lists of environmental capital expenditures for each funding organization, and then to depreciate those expenditures on some agreed timetable (e.g. computers-5 years; microscopes-15 years, lab space-20 years, etc.). Clearly, this would not be an easy job.

2.4 Social Infrastructure

At their core, science and technology are social activities which rely on the interaction of individual researchers, groups, teams, networks, and organizations with their counterparts in Canada and abroad. Thus, the **social infrastructure** of environmental research is another important capacity measure. Earlier, we proposed research personnel as one measure of capacity. Here we propose measures of the social infrastructure in which the individuals operate. Ideally, one would want to record the following types of social infrastructure indicators, in order to build up a picture of national research capacity:

- Number of active environmental R&D organizations[8];
- Number of formal environmental research networks (e.g. relevant Networks of Centres of Excellence);
- Number of multi-institution research teams; and,
- Number of international collaborations (e.g. projects, programs, bilateral agreements, multilateral agreements), as measured using bibliometric techniques (e.g. multi-authored papers).

There are a variety of data sources for these kinds of information, including: Association membership lists; grant databases, bibliometric analyses (e.g. multi-authored papers), and organizational surveys that would determine the number of research agreements (e.g. international agreements). However, these data sources are not in one place, and a

[8]This is somewhat different that the number of research laboratories proposed above. Not all research organizations perform their own research; some fund research that is conducted by third parties.

considerable amount of work would need to be done to collect and collate the appropriate information.

The "quality" of social infrastructure linkages is not synonymous with their quantity. Unfortunately, qualitative indicators of social infrastructure are not currently well developed, and so inferences will need to be drawn from quantitative data.

2.5 Training Infrastructure

The state of Canada's environmental R&D **training infrastructure** is a critical ingredient for assessing national research capacity. Whereas the majority of the training infrastructure is located in universities (and to a certain extent in colleges), it is also important to develop measures of training capacity in government; for example, the number of post-docs receiving environmental research training in federal labs.

The training infrastructure - as measured by such indicators as the number of (environmental) teachers, academic researchers, students, courses, degree/diploma programs, co-op programs, enrolments, degrees/diplomas awarded, schools and faculties, etc. - has two important functions. First, is to provide education and training to the upcoming generation of environmental researchers - scientists, engineers, social scientists, technicians and technologists.

Secondly, the training infrastructure does double duty: it also serves in large part as the academic research delivery infrastructure. In other words, at the same time that students acquire on-the-job research training they simultaneously produce real (environmental) research in collaboration with their supervisors.

Tracking the state of the environmental research training infrastructure and trends in the size and makeup of the infrastructure, is therefore an important aspect of measuring national research capacity. In principle, it should be possible to identify the major training organizations within the university system, which will be the largest research training sector. These organizations will include some obvious examples, such as environmental studies/environmental science programs. Where the exercise becomes more difficult is in tracking training in other sectors - for example chemistry, biology, microbiology - where it is hard to know what component of the training is "environmental". It will be even more difficult to track training or trainees in government, industry or the non-profit sector, than it is in the university sector. Most of these organizations do not keep the kind of records needed, and special surveys would be required to arrive at estimates.

2.6 Ideas

The product of most environmental research - especially university and government research - is **ideas** or knowledge. Ideas are typically associated with academic publications[9] - especially peer-reviewed scientific publications - because that is the form in which they are typically communicated, and because databases for tracking publications are mature and in widespread use[10]. A small subset of ideas - those that are perceived to have commercial value - are translated into patents. Let us refer to academic ideas and patents as "primary ideas".

The knowledge generated by environmental research may in turn be used to produce additional forms of knowledge (e.g. consulting studies, conference proceedings, and other forms of "gray literature") that build on primary knowledge. It may also be used to produce new products, processes or services. We can refer to these as "secondary ideas".

As with research activity, ideas can be viewed both as an output of the research system and as a surrogate indicator of its capacity; if there were a significant increase (or decrease) in knowledge output from the environmental research system, there would be grounds to suggest that system capacity had increased or decreased. Alternately, such changes in output might simply reflect period changes in the "efficiency" of the system. But in any event one would want to measure idea generation as one indicator of system capacity.

Traditional measures of (environmental) ideas have two major sets of indicators: bibliometric outputs (number of publications, citations) and patents. For example, if there was a sustained increase in the number of environmental patents granted in the US to Canadians, we might infer that the capacity of the national environmental research system had improved, and vice versa.

Other examples of ideas as indicators of capacity might include the trend in commercialization activities - the number of ideas being turned into spinoff companies, or licensed to companies to be incorporated into new products and processes.

Bibliometric and patent indicators, though important, do overlook a large body of ideas that do not appear in the peer-reviewed literature: for example, conference proceedings, consultant studies, company/government department reports, and so forth. Unfortunately, there are no comprehensive sources of information on this "gray literature", and so this limitation needs to be taken into account in assessing trends in indeas.

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[9]Especially publications in peer-reviewed scientific journals.

[10]We refer here to the ISI database and its Canadian counterpart which is operated by the OST.

2.7 Conclusion

As the previous discussion implies, it is conceptually easy to identify the 6 factors that make up research capacity. Data and information about the 6 capacity "ingredients" - personnel, research, physical infrastructure, social infrastructure, training infrastructure and ideas - could be used to paint a solid picture of national research capacity. Not surprisingly, the challenge is that there are methodological problems associated with data collection and interpretation for each ingredient.

On their own the individual indicator categories will yield only partial information about the capacity of the environmental research system. None of the categories is dominant enough to fully represent the capacity of the system, so it will be necessary to take a "converging indicators" approach to have a good picture of system capacity.

Point-source information - information about a single year's capacity - is going to be of limited value because there are no standards or points of reference or comparison. For example, we can't judge whether (say) 2,500 environmental research personnel is a good result or a bad result because we have nothing to compare it with. Ideally, we would want to have international norms and comparisons for point-source information, but those do not exist. So, on their own point-source capacity information is of limited value. However, what is most important for understanding capacity is analysis of trends. Point-source (e.g. annual, bi-annual) data about the condition of each element is obviously necessary to understand circumstances at one particular time, but multi-year trend information is what's really needed to understand whether capacity is increasing or declining.

Finally, it is important not to confuse capacity data with capacity information and analysis. Interpreting the meaning and importance of various capacity data is not an exact science, and there is no formula that can be applied to know if capacity is growing or contracting. Analysis is an inherently qualitative activity, and there is ultimately no substitute for knowledgeable individuals reviewing capacity data and rendering a judgement about their meaning.

3.0 SOURCES OF DATA AND INFORMATION

In section 2 above we put forward a conceptual model that can help to describe and analyze environmental research capacity. A real-world capacity assessment exercise would collect relevant data and information about each of the 6 capacity elements that comprise the model - in particular trend information - and make a determination of national research capacity based on them. To the extent that environmental research capacity data are a subset of total research capacity data, in most instances we will need to depend on having access to larger data sets - total research capacity data - to discern the environmental component of the data.

While a conceptual model of environmental research capacity is relatively easy to construct, there are practical problems with teasing out the environmental aspect of research capacity indicators. Foremost among them is knowing in principle what constitutes the "environmental" aspect(s) of each indicator, and then finding actual data for analysis. For example, it is important to know:

- Who are "environmental" personnel and how can they be distinguished from non-environmental researchers;
- What is "environmental" research and how can it be distinguished from other forms of research;
- What is "environmental" physical infrastructure and how can it be distinguished from other R&D infrastructure;
- What is "environmental" research social infrastructure;
- What is "environmental" training infrastructure and how can it be distinguished from non-environmental training infrastructure; and,
- What are "environmental" ideas (publications, patents) and how can they be identified?

The challenge is that unlike more traditional research disciplines, such as physics, chemistry, biology, sociology, psychology, political economy, mathematics, etc., environment is a synthetic, cross-cutting disciplinary concept that draws on the other disciplines. Environmental research is largely applied research; it is research using a variety of disciplines that is applied to solving environmental problems. While some environmental research is so-labelled (e.g. "Environmental effects of substance X") the majority of environmental research is no so clearly labelled. As a rule, data sources are better for established disciplines such as chemistry, than for synthetic disciplines such as environment.

3.1 Delineating Environmental Research

Environment: [1] the surroundings or conditions in which a person, animal, or plant lives or operates. [2] (the environment) the natural world, especially as affected by human activity[11].

Environmental Research and Development - development, evaluation and implementation of clean process technologies and/or end-of-pipe pollution abatement and control technologies, including related consulting engineering and analytical services, and related research to improve knowledge on eco-systems and the impact of human activities on the environment[12].

"If it walks like a duck and quacks like a duck, you can be reasonably sure it is a duck."[13]

3.1.1 A Standard Description and Quantification Matrix

Following the standard OECD approach, an R&D capacity framework will need to distinguish among different aspects of (environmental) science and technology. Science and technology (S&T) encompasses two distinct activities - **Research and Development (R&D)** and **Related Scientific Activities (RSA)**:

Definitions	
Research and Development (R&D)	Systematic investigation carried out in the natural and engineering sciences by means of experiment or analysis to achieve a scientific or commercial advance. Research is original investigation undertaken on a systematic basis to gain new knowledge. Development is the application of research findings or other scientific knowledge for the creation of new or significantly improved products or processes. If successful, development will usually result in devices or processes which represent an improvement in the "state of the art" and are likely to be patentable.
Related Scientific Activities (RSA)	Scientific activities that support research and development, such as data collection, surveys, literature reviews and so forth.
Performance	The R&D or RSA that an organization performs itself (in-house), using its own money or other people's money
Funding	The R&D or RSA that an organization pays a third party to conduct on its behalf

[11]Definition: WordPerfect dictionary

[12]Environment Industry Survey Business Sector, 2000. Catalogue No. 16F0008XIE Environment Accounts and Statistics Division.

[13]Old Adage

These standard descriptions yield a matrix that can be used to quantify (environmental) science activity, as in the following example:

Activity	Performance and Funding (Sample)		
	Performed	Funded	Total
R&D	$100	$200	$300
RSA	$200	$100	$300
Total	**$300**	**$300**	**$600**

So, ideally, for each (environmental) organization we would like to have uniform information about R&D and RSA funding and performance. (See chapter X for a description of data sources). Strictly speaking an environmental research capacity analysis needs to concentrate on R&D indicators, rather than on RSA indicators. However, given the close relationship between the two, in practice one would want to collect data on both sets of indicators to see if they build a coherent picture of capacity.

3.1.2 Defining Environmental Research

There are two cardinal problems that need to be addressed in creating a framework to assess environmental research capacity: (1) Knowing what counts as "environmental research"; and, (2) Developing an environmental research taxonomy - a classification system - that will usefully describe categories or types of environmental research in terms that help assess capacity. The following section talks about different approaches to delineating environmental research from a capacity perspective.

Suppose for a moment that we had before us a complete list of the titles and an abstract of every scientific research project (R&D or RSA) conducted in Canada in a particular year in every discipline, by every performer, whether in the natural sciences, engineering, life sciences, or social sciences. Our intention is to separate out the "environmental" projects, and use the resulting list as a surrogate partial indicator of the country's research capacity[14]. How would we know which projects were "environmental"?

One popular approach is to search for certain **key words** in the title or abstract, such as "environment", "wildlife", "ecology", "climate change" and so forth. This would yield a set of projects that had a high likelihood of being environmental in nature; but it would overlook many more projects that were also environmental. For example, a mechanical engineering project studying the design of an improved stirring device might slip through the key word filter; even if

[14]We use the term "surrogate" because research activity is only an indirect measure of research capacity.

the researcher's intention was to apply the new technology in an improved municipal sewage system.

The keyword approach obviously works best when the focus of the (environmental) research in question is delimited, or when a comprehensive list of keywords is available. For example, it would be easier for a particular organization to create a keyword list covering the areas for which it is directly responsible - pollution, wildlife, climate, etc. - than it would be to develop a keyword list for (say) environmental health or environmental agriculture - fields in which EC is not so heavily involved. When Environment Canada commissions a bibliometric study (of its scientific publishing activities) it is able to specify a finite set of keywords that relate to its own activities, because those activities are comparatively circumscribed.

The previous example also emphasizes the distinction that needs to be made between field of research or discipline (e.g. mechanical engineering) and area of application (e.g. wastewater treatment).

NSERC Environment Categories

- Climate and atmosphere
- Conservation and preservation
- Environment
- Environmental impact of economic activities
- Inland waters
- Land, solid earth seabeds and ocean floors
- Modelling and mathematical simulation of natural processes
- Oceans, seas and estuaries
- Pollutants and toxic agents
- Wildlife management

Though it is a useful and popular approach, the key word approach applied to project titles (or abstracts) does have obvious limitations. It is very difficult to specify all the key words that would filter out (or in) every environmental research project from the universe of research projects. And, one would still need to discern the researcher's intent - the field (i.e. environment) in which the researcher intends to apply the findings. Thus a second approach to discerning environmental research projects is to ask researchers to self-categorize their research. At least one federal Granting Council - NSERC - does address this problem by asking its researchers to designate an area of application when they are submitting grant requests, and offers a number of choices under the Environment application heading. SSHRC will shortly release its own database with comparable information. However, other research organizations tend not to collect information on area of application. And if they do, they may not use the same categories as NSERC or SSHRC do[15].

The key word approach works best when there is a comprehensive database of research that can be "filtered" using key words. Comprehensive databases are well developed for peer-reviewed scientific publications[16] and in some instances for research grants, scholarships and

[15] In other words, if Environment Canada maintained a database of all research it performs and funds (to the best of our knowledge it does not have such a database) it would probably use definitions or categories that were different from those used by NSERC. The two categories would not be directly comparable.

[16] The best example in Canada is the OST/ISI citation index of peer-reviewed scientific literature.

fellowships. But there are no comprehensive databases for research activity in government or industry, which makes the key word approach less useful there. Helpful as the key word approach can be, it is not without difficulties:

1. Not all organizations maintain comprehensive lists of their (environmental) research activities;

2. Not all research funders (NSERC is an obvious exception) require applicants to specify an area of application for their research;

3. Not all research funders make area of application information available to third parties;

4. There is no universal or generally accepted system for classifying environmental research, either within any particular field (e.g. life sciences), or among fields (e.g. life sciences versus engineering); and,

5. Different organizations use different classification systems.

So, while in practice it is straightforward to use a keyword approach to delineate environmental research, there are many practical problems that need to be overcome.

3.1.3 Sources of Environmental Research Data

In practice, each individual organization tends to develop its own classification system - if they have any at all - and the resulting classification systems cannot easily be compared or combined. In practice as well, few research funding organizations have comprehensive lists of research projects and make these available for public consumption. For example, while Environment Canada maintains a wide variety of databases it has none on environmental research - even its own research.

As indicated, there is no ready-made central list of research funded or performed by Environment Canada. To develop such a list individual EC directors would need to be canvassed for the research projects that they are performing or funding. To know what research that EC was funding or performing in a particular year, one would likely need to conduct a survey of directors to collect the information. (The same considerations likely apply to other federal SBDAs[17]). So, what we are likely to find is that most organizations - whether they operate in the industry, university, government or non-profit sectors - do not maintain up-to-date , publicly available lists of the research they fund or perform, and fewer still have systems to categorize which of their research activities are "environmental". And, even if they wanted to categorize their research, there is no universally agreed scheme - typology - that can be used for this purpose.

[17]Science-Based Departments and Agencies

So, on the two issues posed earlier - (1) Specifying what counts as "environmental research" and (2) Developing an environmental research taxonomy - we conclude that there are difficulties with each:

Issue	Problem
Specifying "environmental research"	• Many key information sources (e.g. SBDAs) have no consolidated lists of research funded or performed • Most existing lists (NSERC is an exception) do not designate or distinguish "environmental" research • Difficulty in knowing whether research is environmental or other
Developing an environmental research taxonomy	• No universal classification system • Different organizations use different systems

Compounding these problems is the fact that "environment" itself is a synthetic discipline, combining elements of chemistry, biology, physics, mathematics, etc. So, even if one had a complete list of all research being conducted in a particular year, it is obvious that there would be great practical difficulty in classifying the research in thematic environmental terms. (For similar reasons, it would be difficult to classify other desirable environmental indicators, such as the number of environmental researchers, publications, patents, etc.)

That is not to say, however, that by making certain compromises in definitions and data collection methods, that one cannot arrive at reasonable estimates of activity. Organizations such as Statistics Canada regularly make such compromises when collecting information; for example, in defining a company's industrial classification by the sector in which it produces a majority of goods or services, in dollar terms. Companies that produce 51% of a certain good or service in Industry A, and 49% in Industry B will be classified as if all their production was in Industry A. Take the example of CAE Industries. Until recently, CAE had an electronic products division which manufactured aircraft flight simulators, and an industrial products division which manufactured equipment for the pulp and paper industry. How then to describe CAE? The idea is that over a large number of companies the compromises will average out and the result will represent a true picture of activity. What is equally important is that data collection activities employ a consistent set of definitions, because in many instances it is as important to measure trends (e.g. in expenditure) as it is to measure (say) actual expenditure at any point in time.

The "holy grail" of environmental research capacity analysis - in which analysts simply compile data from existing databases that are supplied by research funders and performers, and that are accurate and comprehensive - does not exist. There are a limited number of reasonably good databases (e.g. NSERC, OST/ISI), but these are the exception to the rule. Even where there are good databases, a considerable amount of work needs to be done to tease out "environmental" projects. In other instances (e.g. Environment Canada research, other SBDAs, industry research) it would be necessary to take a bottom-up approach in which each funded or performed project is individually reviewed and coded using an appropriate taxonomy or coding system.

3.2 Environmental Research Taxonomy

Would it be helpful if there were a simplified, standard framework for analyzing environmental research capacity? In section 3.1.2 above we talked about the utility of an environmental research taxonomy - a standard framework for categorizing environmental research. We pointed out that few organizations have schemes for distinguishing environmental research from other research they might fund or perform. NSERC was one exception; it has developed its own taxonomy. Another exception is the taxonomy that is now being developed for Environment Canada's ECXpert database[18]. However, this confirms the core problem, which is that there is no standard system for classifying environmental research and each organization tends to have its own classification system. But, there is no uniformity among the different systems. Thus, the scheme that NSERC uses when asking researchers to identify the area of application of their research (see right) is one example of a thematic approach to classifying environmental R&D. Different organizations would develop different approaches.

The NSERC classification scheme is a thematic framework for classifying environmental research. It reasonably describes a variety of different environmental themes - economic impacts, inland waters, wildlife, oceans, etc. - of the research in question. But the thematic approach does little to advance understanding of the focus of this study, which is capacity - the potential (of the research system) to conduct environmental research. Capacity analysis requires a different approach, one that complements the thematic approach.

Environmental Capacity Analytical Approach	
Sub-Theme	**Description**
Characterization and monitoring	Projects are aimed at understanding, characterizing or monitoring an environmental issue (e.g. CO^2 levels, bird populations, water quality, human effects, etc.)
Prevention	Projects are aimed at preventing an environmental problem (e.g. pollution, GHG emissions)
Remediation	Projects are aimed at repairing or remediating an environmental problem (e.g. oil spills, mine acid drainage, etc.)

From the perspective of measuring environmental research capacity, we need to blend a thematic approach (air, land, water, etc.) with one that provides useful information about research capacity. Table 1 following provides a sample capacity analysis framework. The

[18]The ECXpert database is intended to be a "yellow pages" of internal EC expertise.

framework proposes 3 sub-themes designed to tease out the capacity aspect of research in different research fields. The 3 capacity themes are **characterization and monitoring**, **prevention**, and **remediation**. Ideally, we would want to be able to describe Canada's environmental research system in terms of its capacity to: (a) characterize or monitor, (b) prevent, or (c) remediate environmental research in the different theme areas; air, water, land, etc.

Using this approach we can also classify the type of research being undertaken: whether it is science, technology development, social science, or interdisciplinary.

The advantage of this approach is two-fold. First, it simplifies the taxonomic problem (too many different descriptive categories and no consistency among different classification systems) by focussing on a limited number of "big" application themes (animals, people, ecosystems, etc.). Secondly, it yields information about the capacity of the research system in each major theme area in terms that are useful for policy, planning and priority-setting, rather than simply for descriptive purpose, by determining whether the research involves monitoring/ characterization, prevention, or remediation. For instance, simply knowing that a certain level of research effort is being devoted to research in the field of (say) air particles, is less valuable than knowing that a certain proportion of air research is devoted to characterizing air (particulate) problems, preventing them, or repairing them. The same applies to the other environmental research themes.

However, the problem with this approach is that it too is not standard. Even in organizations such as NSERC, that track environmental research separately, it would be necessary to re-code the various research projects so that they could be fit into this framework. Clearly, this would be a daunting task that could only be handled manually. The lesson is that even an "improved" classification system introduces its own challenges, due to the need to code or re-code research activities to fit into the capacity assessment framework.

Table 1. Environmental Science Capacity:
Capacity Analysis Framework

Environmental Research Theme	Sub-Themes	Type			
		Science	Technology Devp't.	Science, Governance, Society	Inter-Disciplinary
Air	Characterization, Monitoring				
	Prevention				
	Remediation				
Land	Characterization, Monitoring				
	Prevention				
	Remediation				
Water	Characterization, Monitoring				
	Prevention				
	Remediation				
People	Characterization, Monitoring				
	Prevention				
	Remediation				
Animals	Characterization, Monitoring				
	Wildlife				
	Domesticated animals				
Plants	Characterization, Monitoring				
	Prevention				
	Remediation				
Ecosystems	Characterization, Monitoring				
	Prevention				
	Remediation				
Climate Change	Characterization, Monitoring				
	Adaptation				
Interdisciplinary Science	Theoretical science				
	Applied science				
Environmental Technologies	New technologies				
	Technology improvement				
Society, Governance and Behaviour	Analysis				
	Prescription				
Environmental Research Infrastructure	Analysis				
	New models and approaches				

4.0 DEVELOPING A WORKABLE CAPACITY ASSESSMENT SYSTEM

The previous discussion has pointed to the many difficulties inherent in constructing a comprehensive system for assessing national environmental research capacity. With an unlimited amount of time and money many of these could be overcome, but at a high cost. Is there an approach that can produce useful information about environmental research capacity with a reasonable amount of effort? Table 2 following summarizes a generic approach that could be used to build a picture of environmental research capacity. Here we discuss the proposed approach.

4.1 Personnel Capacity

Environmental research personnel is a key factor in assessing capacity. Essentially, there are two personnel categories that need to be assessed: active researchers and research students (graduate students and post-docs).

Key indicators for active researchers are: the number of university researchers receiving (environmental) research grants from the 3 Granting Agencies[19], and the number of environmental researchers working in government and industry. Similar indicators for research students are: the number of graduate students conducting environmental research as a proportion of all graduate students, trends in graduate student enrolments, and the number of graduate students and post docs working in federal environmental labs.[20]

Data sources include the Granting Agencies (research grants, strategic grants, scholarships, fellowships), Canada Research Chairs Secretariat, Statistics Canada (government, industry researchers, annual higher education survey) and possibly occasional surveys that might be conducted to fill in information gaps.

Assessment measures would be: the number of environmental researchers as a proportion of all researchers, and trends in the number of researchers in universities, industry, government.

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[19]NSERC, SSHRC, CIHR

[20]However, it should be borne in mind that there are doubtless a number of researchers who do not receive grants from the Councils who might still be conducting environmental research. Therefore, Council data should be regarded as minima.

Table 2. Environmental Research Capacity Model				
Capacity Element	**Description**	**Indicators**	**Assessment Measures**	**Data Sources**
Personnel	Active researchers	• # of Granting Council recipients • # of government researchers • # of industry researchers	• Actual # of environmental researchers • Environmental researchers as a proportion of all researchers • Trend in # of grant recipients • Trend in # of univ. researchers • Trend in # of gov't researchers • Trend in #of ind. researchers	• Granting Agencies • Canada Research Chairs • StatCan environmental industry survey • StatCan annual survey of federal government S&T • Occasional surveys (gov't., industry)
	Research students	• # of Masters and Doctoral students • # of post-docs	• Actual #of environmental graduate students • Environmental grad. students as a proportion of all grad students • Trend in grad. student enrolments • # of grad. students and post docs working in federal environmental labs	• Granting Council scholarship/ fellowship data • StatCan Higher Ed. Survey
Research Activity	Funding: R&D projects and programs funded	• Gov't., Univ., Industry: ▸ # of research projects funded ▸ $ value of projects funded ▸ # of research programs funded ▸ $ value of programs funded	• Actual # of research projects funded • Trend in # of research projects • Trend in $ value of research projects • Trend in # of research programs • Trend in $ value of research programs • Analysis of trends and distribution of funding for different research themes	• Granting Council data • StatCan surveys and estimates (Fed., Prov., Ind., Univ.) • Special surveys (esp. federal gov't.)
	Performance: R&D projects and programs performed	• Gov't., Univ., Industry: ▸ # of research projects performed ▸ $ value of projects performed ▸ # of research programs performed ▸ $ value of programs performed	• Actual # of research projects performed • Trend in # of research projects • Trend in $ value of research projects • Trend in # of research programs • Trend in $ value of research programs • Analysis of trends and distribution of performance for different research themes	• Granting Council data • StatCan surveys and estimates (Fed., Prov., Ind., Univ.) • Special surveys (esp. federal gov't.)

Capacity Element	Description	Indicators	Assessment Measures	Data Sources
Physical Infrastructure	Environmental research facilities and equipment	• # of env. R&D laboratories • Capital investment in facilities and research equipment	• Actual and depreciated cost of physical infrastructure • Replacement cost of physical infrastructure • Trend in # of env. R&D laboratories • Trend in capital investment in plant and equipment	• Occasional survey • StatCan surveys
Social Infrastructure	Networks, teams, alliances	• # of env. R&D organizations • # of env. research networks • # of multi-institution research teams • Bibliometrics - # of international collaborations • # of international agreements	• Actual # of research networks • Trend in # of research networks • Trend in # of multi-institution teams • Trend in #, type and distribution of international collaborations	• Granting Council funding (e.g. NCE, Strategic Grants) • OST/ISI data on multi-authored papers • DFAIT data • Occasional surveys
Training Infrastructure	Environmental research education infrastructure in universities, colleges and government organizations	• # of schools and faculties • # of university graduate E.S. programs • # of teachers • # of students enrolled • # of courses • # of co-op programs • # of degrees/diplomas awarded	• Actual # of graduate and undergraduate programs • Trends in # of graduate programs • Trends in # of undergrad. programs • Trends in enrolments • # of graduate students & post-docs in government & industry	• UofA Environmental Research and Studies Centre Online (www.ualberta.ca/~ersc/) • Can. Graduate Programs in Environmental Studies (Queen's U.) (http://www.queensu.ca/envst/envsgrad/) • AUCC directory • Occasional surveys
Ideas	Research outputs	• Bibliometrics - one author • Bibliometrics - multiple authors • Bibliometrics - Inter-institutional collaborations • International collaborations • Patenting activity • Licensing activity • Spinoff company creation	• Actual number of publications (single, multiple, inter-institutional) • Trend in publications (single, multiple, inter-institutional) • Trend in domestic collaborations • Trend in international collaborations • Trend in patenting activity • Trend in licensing activity • Trend in new products introduced • Trend in spinoff company formation	• ISI bibliometric data (OST) • Patent databases (Can. + US) • AUTM Canada data • University ILOs • Granting Council stats • StatCan environmental industry survey • Special surveys

4.2 Research Activity

Key indicators of research activity should be collected both for R&D projects (individual research efforts) and programs (sets of research projects) and data should be collected both on funding and performance.

Funding assessment measures for research activity would include: the actual number and trends in research projects funded and the dollar value of research in different categories (air, land, water, etc.).

Funding data sources would be the Granting Agencies, annual StatCan surveys[21] (federal, provincial, industry, university S&T and R&D surveys), and special surveys that would likely need to be commissioned, especially to collect information about federal funding.

Similar information can be collected for **research performance**, using similar indicators and sources of data.

4.3 Physical Infrastructure

Physical infrastructure will be one of the most difficult capacity elements to measure, as there are few if any data kept on this indicator. As a result, a special study will almost certainly be needed. It is possible that this could be undertaken in partnership with Statistics Canada.

Appropriate physical infrastructure **indicators** would include the number of environmental laboratories (defined as labs mostly dedicated to environmental research), and annual capital investment in facilities and major equipment. **Assessment measures** would include the actual and depreciated value of the physical infrastructure, and its replacement cost. Trend data on the number of labs and capital investment would also be desirable.

With respect to **data sources**, as indicated above, these will be problematical. It is possible that Statistics Canada could tease out some capital investment data either from their annual survey of industrial R&D, or that survey in combination with other StatCan data.

4.4 Social Infrastructure

Social infrastructure would focus on measuring the condition of environmental research networks, teams and alliances. Key **indicators** would include the number of environmental research organizations, formal research networks, multi-institution teams. **Assessment measures** would include: the number of research networks, multi-institution and international teams and collaborations, as well as trends in teams and teaming. **Data sources** are problematical. Some information can be collected from the Granting Agencies (e.g. strategic

[21] Some StatCan surveys collect information concerning the area of application of research, but others do not.

research grants, research network grants) and Networks of Centres of Excellence. DFAIT might have some data on international collaborations. However, it would probably be necessary to conduct a separate survey to collect good information on social infrastructure.

4.5 Training Infrastructure

Training infrastructure is concentrated in universities, colleges and government organizations. **Key indicators** of training infrastructure include: the number of (environmental) schools and faculties and number of graduate programs in environmental studies. Associated indicators are the number of teachers/professors, number of students enrolled, number of courses taught, number of co-op programs, and importantly, the number of degrees and diplomas awarded.

In terms of **assessment measures**, one would want information about the actual number and trend of graduate and undergraduate programs, courses, and enrolments. Also helpful would be information about the number of graduate students and post-docs pursuing their studies in government and industry settings.

Data sources include the University of Alberta Environmental Research and Studies Centre[22], and Queen's University Canadian Graduate Programs in Environmental Studies directory (http://www.queensu.ca/envst/envsgrad/). Other information can be gleaned from a review of the AUCC university directory, and from occasional surveys that might be commissioned.

4.6 Ideas

Some of the better information about environmental activity is available for publications and patents. **Key indicators** for ideas include: bibliometric data (single author, multiple authors, international collaborations), as well as patenting data, spinoff company data and technology licensing information. Useful **assessment measures** would include: number of (environmental) publications, type of publications (single, multiple authors, etc.), trends in international collaborations, trends in patents, technology licenses, new products, and spinoff company formation. **Data sources** include the OST/ISI bibliometric database (for publications), Canadian and US patent databases, Granting Council statistics, Statistics Canada's environmental industry survey, information produced by AUTM Canada (Association of University Technology Managers) and information available from individual university and government department Technology Transfer/Industry Liaison offices[23].

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[22]This comprehensive resource and links site is designed for: Scientists seeking information on environmental research programs and researchers; Students seeking information about environmental studies programs, courses, and careers; Teachers seeking science-based resource materials for their classrooms; and, Citizens seeking information about current environmental issues in Alberta, Canada and the World.

[23]These produce annual reports that contain much useful information on technology transfer.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

As discussed throughout this report, fully implementing a framework to assess environmental science and technology research capacities will not be simple, fast or inexpensive. There are many conceptual and practical problems that need to be worked through, and many uncertainties to be overcome. Some data sources are readily identifiable while others are not. Nevertheless, we believe there is a sufficient body of data and information available that a pilot project could paint a useful picture of national capacity. The challenge will be to pick the "low-hanging fruit" - the information that can be easily gathered - and to supplement this approach with some targeted special research projects.

We need to bear in mind that raw data on their own will be of limited use in interpreting the national capacity for environmental research; the data need to be placed in context. One important context is international - comparing the Canadian situation with that of other countries: a capacity study will be less useful if comparable data are not available for countries with which Canada would want to compare itself[24]. Without international comparisons we will not be able to benchmark the Canadian situation - to know how well we are doing.

Data that measure national environmental research capacity at one point in time will also be of limited use; most important will be trend information. Trend information (time series data) will require a sustained effort over a number of years to collect. Environment Canada will need to consider whether it is willing to commit itself to a multi-year effort of the type that will provide trend data, in order to know if Canada's situation is improving, declining, or staying the same.

In addition, capacity studies will be of limited value unless there is an obvious use for the information, such as supporting a national environmental research capacity strategy. Capacity information will be much more useful if we know what we want to achieve in terms of developing the country's environmental research capacity, and this will require a strategy. Of course, there is a chicken-and-egg problem here, and we also acknowledge that to a certain extent capacity information may be needed to develop a strategy.

Finally, we caution against the common desire to collect information "just in case" it might be required rather than because it is required. Any capacity studies need to pass the "how are we actually going to use the information" test, to avoid collecting information that won't be used.

[24]There is no indication that other countries are much better positioned than Canada to produce comparable information.

5.2 Recommendations

Table 3, following, outlines a recommended environmental research capacity assessment program. The program takes into account the priority of each capacity element (personnel, ideas, etc.), how easy or hard it will be to collect data for that element, likely assessment approaches, and estimated costs and time frames to complete the work. The result is that there are 10 capacity elements deemed as "high priority", and where there are reasonably good data sources. Collecting information about each of these is recommended.

Recommended Capacity Studies

1. Researchers: university, government, industry
2. Graduate students in environmental research programs;
3. University and government research funding;
4. University and government research performance;
5. Social infrastructure (pilot feasibility project);
6. Training infrastructure;
7. Bibliometrics
8. Patents
9. University spinoff companies
10. Synthesis of results (studies 1-9)

Information and concepts related to social infrastructure are not presently well developed. However, as this is a potentially important area of research capacity, we recommend that a special pilot project be undertaken to establish the feasibility of collecting social infrastructure indicators.

Once the results of the specific capacity studies are available, they will need to be combined into a synthesis report. Such a report is the final one that is being recommended.

We estimate that completing all phases of the work would cost in the order of $200,000 if, as assumed, all work is contracted out rather than done in-house. The plan will also require the cooperation of external organizations (such as the Granting Agencies and other government departments). If Environment Canada wishes to undertake parts of the work internally, then costs will be reduced accordingly. The plan will take approximately 12 months to implement fully.

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Table 3. Environmental Research Capacity Plan

Capacity Element	Priority	Indicator Availability (High, Medium, Low)	Assessment Approach	Estimated Cost	Time Frame	Capacity Study Recommended
Personnel	High (Researchers)	Medium-High	• Review of Granting Council grant data • Review of StatCan federal S&T and R&D data		3-6 months	**Yes**
	High (Students)	Medium-High	• Review of Granting Council scholarship, fellowship, PDF data	40,000	3-6 months	**Yes**
Research Activity	High (Funding)	Medium-High	• Review of Granting Council data • Review of StatCan data • Special federal government survey		3-6 months	**Yes**
	High (Performance)	Medium-High			3-6 months	**Yes**
Physical Infrastructure	Low	Low	• Re-analysis of StatCan data • Special survey	50,000	6-9 months	**No**
Social Infrastructure	Medium	Medium-Low	• Bibliometric analysis • Review of Granting Council data • Review of international S&T agreements	20,000	3-6 months	**Yes (pilot study)**
Training Infrastructure	High	Medium-High	• Review of *Canadian Programs in Environmental Studies* • Special study • Review of Granting Council data	30,000	3-6 months	**Yes**
Ideas	High (publications)	Medium-High	• Key-word bibliometric analysis	15,000	3-6 months	**Yes**
	Medium (patents)	High	• Analysis of Canada/US patents	20,000	3-6 months	**Yes**
	Medium (licensing/ spinoffs)	Medium-High	• Review of AUTM Canada data • Survey of university ILOs	10,000	3 months	**Yes**
Synthesis of Results	High	As above	As above	20,000	3 months	**Yes**
			Total	**$205,000**	**12 months**	

Note on availability: High=immediately available, Medium=some re-analysis required, Low=original research required

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