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University Data Centres: Policy and business case for reducing greenhouse gas emissions

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http://www.iisd.org

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IISD gratefully acknowledges the support of Canada's Advanced Research and Innovation Network (CANARIE) (www.canarie.ca).

Published by the International Institute for Sustainable Development

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Executive Summary

The goal of this project is to assess the feasibility of reducing greenhouse gas emissions and generating carbon offsets via the relocation or modification of University Information and Communication Technology (ICT) assets leveraging Canada's Advanced Research and Innovation Network (CANARIE). In particular, the study investigates (1) moving University data centres to remote, zero-carbon (i.e., powered with renewable energy) facilities; (2) relocating the data centres to urban settings in provinces with low-emission electrical grids and where waste heat from the data centre can be utilized effectively; and (3) modifying the existing data centre to capture and utilize waste heat. Upon analyzing these scenarios, it was determined that only the third, in one case, would generate sufficient revenue from the sale of carbon credits to overcome the expense of the project.

This study also investigates the option for co-locating or consolidating multiple data centres, allowing their optimization and more efficient and effective operation through virtualization, best practices and economies of scale, ideally in a green community cloud configuration.[1] This project also aims to better inform University ICT managers and administrators of potential revenue resulting from such a configuration and to support the greening of University ICT activities. Policy-makers outside the University system also are encouraged to consider this project's recommendations for enhancing incentives or addressing disincentives to support the greening of data centres.

Three Universities volunteered to participate in this study and provide input, feedback, expertise and data pertaining to their main data centres and other aspects of their ICT systems and administrations. These institutions were Dalhousie University, in Halifax, Nova Scotia; the University of Ottawa, Ontario; and the University of Alberta, in Edmonton, Alberta. A kick-off meeting to introduce project participants, hold interviews and conduct a site tour was completed, with relevant ICT and administrative personnel on site at each of the Universities.

Following the principles of ISO 14064-1 to the extent possible, the carbon footprint for the main data centres at each University was completed. To limit the complexity of this study, only the main ICT data centres designed and operated to host each University's mission-critical systems were evaluated. The annual carbon footprint ensuing from the operation of all three data centres combined was 11,305 tonnes of carbon dioxide equivalent (CO_2e)—Ottawa, 1,007; Dalhousie,

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[1] A green community cloud is composed of one or more data centres having a combination of partitioned (private University) areas and shared information technology (IT) systems provisioned as cloud services such as storage, high performance computing (HPC) and servers. Data centres within the community cloud would be required to operate exclusively in provinces having low electricity grid emission intensity, have high power usage efficiency, make maximum reuse of waste energy, and minimize the impact on the local environment.

5,010; and Alberta, 5,288—the entirety of which is the result of electricity consumption for the ICT equipment, cooling and auxiliary systems.

The volume of carbon credits available under the first scenario was: Ottawa, 2,207; Dalhousie, 11,949; and Alberta, 9,563 tonnes of CO_2e, which translated into average net annual carbon credit revenues of CAD$60,125 for Ottawa, $405,161 for Dalhousie and $320,642 for Alberta. Expenses, on the other hand, were very high for this scenario, due to the large capital expenditures required in order to build a data centre and power plant. The resulting net present values (NPVs) were not positive for any of the Universities, at $(8,535,093) for Ottawa, $(6,968,567) for Dalhousie and $(8,448,132) for Alberta.

The analysis of the case for each University under the second scenario also resulted in a negative NPV. Under this scenario, the volume of carbon credits generated was 1,697 tonnes of CO_2e for Ottawa, 5,812 for Dalhousie and 7,470 for Alberta. These volumes translated into estimated average net annual carbon credit revenues of $42,035 for Ottawa, $187,486 for Dalhousie and $246,414 for Alberta. The increase in the volume of carbon credits available between Scenario 1 and Scenario 2 results from the inclusion of credits generated due to the displacement of fossil fuel heating—in an urban setting (as opposed to the remote location from the first scenario), it was assumed that a use for the waste heat from the data centre could be found. Expenses were significantly less because the cost of constructing and operating a renewable energy facility was not required; however, once again, none of the scenarios resulted in a positive NPV, with values of $(3,401,831) for Ottawa, $(2,682,716) for Dalhousie and $(3,616,477) for Alberta.

In the third and final scenario, costs and revenues are the least of any of the three scenarios, and the resulting NPV analysis is positive for the University of Alberta. Approximately 701 tonnes CO_2e (carbon credits) were available for Ottawa, 814 for Dalhousie and 2,198 for Alberta. This is generally lower than the other two scenarios because credits are only generated via the displacement of fossil fuels. This volume of credits was estimated to generate annual average net carbon credit revenues of $6,742 for Ottawa, $10,243 for Dalhousie and $59,455 for Alberta. Expenses were far lower than in the other two scenarios, with the only substantial cost expense being the installation of the necessary metering and heat transfer equipment. Therefore, in this scenario, the NPV values were negative for Ottawa $(95,128) and Dalhousie $(76,374), but positive for Alberta, at $189,579.

Based on the results described above and discussions with the University personnel, a further concept—that of co-locating the data centres (in particular, a green community cloud formation)—was analyzed. Ultimately, this investigation found that although the economics for generating revenue via carbon credits from data centres was generally not attractive for the individual Universities studied, a green community cloud data centre operated and administered by CANARIE has numerous other benefits and is more likely to be economically beneficial, presenting a perhaps ideal opportunity for CANARIE to leverage its position and provide leadership to its membership and the Canadian ICT sector in general.

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Introduction

This section provides some background context relevant to University Information and Communication Technology (ICT) infrastructure and its relationship to greenhouse gas (GHG) emissions in Canada, an outline of this project's objectives and a description of the project and its participants.

Context

Even though computers are shrinking in size and using less power to perform more tasks in less time, a greater number of computers are being deployed in data centres to respond to the ever-increasing demand fuelled, in large part, by Internet applications such as search engines, email, online data storage and backup, and increasing numbers of online applications offered through cloud computing. Developing countries are just beginning to enter the Internet age and thus, even with aggressive implementation of efficient technologies, the ICT footprint is set to grow at a rate of 6 per cent each year until 2020.[2]

In 2007, the total GHG footprint of the ICT sector—including personal computers and peripherals, telecom networks and devices, and data centres—was 830 megatonnes of carbon dioxide equivalent (Mt CO_2e), about 2 per cent of the estimated total emissions from human activity released that year. By themselves, data centres emitted an estimated 116 Mt CO_2e, representing 14 per cent of the total 2007 ICT emissions.[3]

According to Greenpeace International, the derived electricity consumption for data centres in 2007 was 330 billion kilowatt-hours (kWh); this is forecasted to grow to 1,012 billion kWh by 2020.[4] The electricity running the ICT equipment typically only represents about half of the power usage in a data centre. A portion of the ICT equipment power is converted to heat, and because ICT equipment specifications commonly suggest operation at temperatures ranging from 16°C to 24°C, powerful air conditioning and cooling systems are required to chill the hot air expelled by the servers and storage systems. These cooling systems use about one-third of the data centre energy. Finally, auxiliary systems, lighting and energy loss by various equipment account for approximately 17 per cent of the energy used in a data centre.[5] To lower ever-increasing operating costs, large data centre

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[2] See "SMART 2020: Enabling the low carbon economy in the information age," 2008, a report by The Climate Group on behalf of the Global eSustainability Initiative (GeSI), available at www.Smart2020.org.

[3] The Climate Group, "SMART 2020."

[4] See "Make ICT green: Cloud computing and its contribution to climate change," 30 March 2010, available at www.Greenpeace.org.

[5] J. Koomey, K. G. Brill, W. P. Turner, J. R. Stanley and B. Taylor, September 2007, "A simple model for determining true total cost of ownership for data centers," Santa Fe, NM: The Uptime Institute, available at www.uptimeinstitute.org.

operators are now focused on improving the efficiency of their facilities by reducing both the electrical power required to cool the ICT equipment and wasted power in underutilized ICT equipment. These efficiencies are gained by designing buildings that make better use of outside air to cool the equipment (free cooling) or waste heat (from the ICT equipment), by taking advantage of technological advances in the ICT sector such as virtualization, and by implementing layouts that improve air handling and efficiency.

GHG inventorying and accounting is becoming more common across sectors and geographies. Debate surrounds the question of how best to reduce the concentration of GHG in our atmosphere—in particular, the merits of a carbon tax or a cap-and-trade system are often compared. Two cap-and-trade bills have been introduced in the United States which, if signed into law, would require certain industries to meet absolute emission targets;[6] the Canadian government has indicated that it intends to follow whatever path the United States chooses. In the current American political climate, however, the prospects for a cap-and-trade bill to pass are marginal at best.[7] Regardless, while standardized approaches to GHG accounting exist, the field is evolving rapidly, and conflicting or unclear guidance is common.

Objectives of research

The objectives of this project are to:

- calculate or estimate, depending on data availability, the aggregate carbon footprint of ICT assets and associated data centres at three Canadian Universities;
- assess the feasibility for Universities to generate carbon offsets if their ICT departments were to relocate or modify their operations so as to reduce their carbon footprint and, in the process, reduce emissions;
- assess the feasibility of quantifying and selling these emission reductions (carbon credits, offsets) in registries and carbon exchanges;
- assess the business case for University ICT departments to relocate or modify data centre facilities, with attention to the role of offset revenues if accessible to the relevant business unit;
- assess the implications of study findings for scaling similar ICT asset relocation or modification schemes for government agencies and institutions, as well as for the private sector; and

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[6] The Waxman–Markey bill was approved by the House of Representatives in mid-2009, while the substantially similar Boxer–Kerry bill was released in the fall of the same year. The most recent bill (Kerry–Lieberman) was introduced in mid-2010.

[7] "Let it be: The Democrats abandon their efforts to limit emissions through legislation," *The Economist*, 29 July 2010.

- recommend policy changes to enhance incentives or address disincentives to support scaling the relocation or modification of ICT assets, possibly by:
    - encouraging University policies to consider long-term implications of their ICT asset growth projections and to harmonize organizational boundaries around accounting practices for facilities expenditures, energy consumption and GHG emissions;
    - addressing jurisdictional barriers resulting from data security policies and capital financing rules to the migration of University, other public sector, and private sector ICT infrastructure and services;
    - encouraging greater consideration of the implications and opportunities of energy intensive, yet relatively location insensitive, ICT infrastructure and services for energy and GHG policy at provincial/federal and international levels; and
    - encouraging national broadband and CANARIE policy that support cost-effective access for remote relocation of ICT infrastructure and services.

Many have suggested that the ICT sector could play a major role in moving toward a greener economy; however, little attention has been paid to determine whether the right policy incentives are in place to facilitate and encourage this. Therefore, by analyzing the policy environment for specific ICT asset relocation initiatives, this project aims to achieve a practical demonstration of the kind of role ICT could play in moving toward a greener economy and encourage more practical and innovative thinking into how the ICT sector could contribute to tackling the challenge of climate change. The findings in this study may also inform how the co-location of other public sector and private sector ICT infrastructure and services with remote sources of renewable energy could be encouraged as part of national and international incentives for achieving GHG reductions.

Ultimately, the premise of this project is that optical communication networks like CANARIE make it possible to design greener data centres by taking advantage of remote or low-emission sources of clean energy while funding the project via the extra revenue gained from selling offsets. The aim of this study is to generate data to assess the above premise, as well as assess the impact of any unanticipated barriers uncovered during the study and existing GHG policy, and possibly open the door to the widespread acceptance of green data centre design as a policy that should be broadly embraced and officially supported.

Project description

The project has been divided into two phases of work, described below. This report integrates the findings for both phases.

Phase I

In the first phase, the aggregate carbon footprint of ICT assets in the main data centres at three Canadian Universities was calculated (or estimated, depending on data availability). These data centres were generally larger, enterprise class data centres (though the findings may also apply to smaller data centres). It is also important to note that, in order to limit the complexity of this study, only the main ICT operation rooms designed and operated to host the University's mission-critical systems were considered.

Options, requirements and cost estimates for the relocation of ICT assets, leveraging CANARIE, were also assessed. The carbon footprint of the relocated or modified data centres were estimated and compared with status quo emissions to estimate the GHG emission reduction that could be achieved with the relocation or modification of the ICT assets.

Phase II

In the second phase of this project, a policy and carbon market scenario analysis characterizing the nature and magnitude of carbon finance opportunities available to the Universities under the scenarios described was completed. In addition, a more in-depth analysis of policy linkages for relevant stakeholders (such as University ICT departments, all levels of government and granting agencies) was conducted.

It is likely that significant barriers to realizing carbon finance opportunities for such initiatives would exist beyond the domain of GHG policy. Therefore, unanticipated barriers uncovered during the course of the study were also explored. For instance, during the project kick-off meetings, numerous barriers to the relocation of data centres to remote, off-grid facilities were expressed by the participants, including:

- revenue from GHG offset credits generated would be small compared to the cost of relocation;
- numerous plans to increase the efficiency and effectiveness of University data centres are already in place;
- concerns exist regarding the management, access and security of University data stored at remote sites; and
- the ability to purchase green energy to operate the data centres already exists.

In fact, this feedback led to further investigation of how cloud computing could be implemented leveraging the existing (CANARIE) network. Creating a green community cloud, to be shared by Universities across a region—or even throughout Canada—would likely provide a greater opportunity to realize efficiencies, utilize renewable energy and take advantage of waste heat. The green community cloud ("community cloud") would consist of a data centre operated by CANARIE and connected to its network, located in a province with low electrical grid emission intensity (for instance, provinces with significant hydroelectric resources like Québec, British Columbia or Manitoba).

Because community clouds offer on-demand resources, their use also has the potential to substantially reduce the quantity of systems deployed (shared, virtualized, optimized) and thus would further reduce costs and energy consumption. Universities would benefit from sharing resources—made possible by CANARIE's high-speed network.

CANARIE could take the leadership role in developing the community cloud data centre (potentially with commercial partners), while user institutions would provide operational funding. If desired, the facility could also be split into a combination of co-location and cloud resources to allow institutions to have a physically separate facility to set up highly proprietary systems.

Participants

The project involves three Canadian Universities: Dalhousie University (Halifax, NS), the University of Ottawa (Ottawa, ON) and the University of Alberta (Edmonton, AB).

University of Ottawa, Computing and Communications Services

Through the leadership of the Chief Information Officer, Computing and Communications Services is responsible for planning and strategy institution-wide; analyzing and reworking existing business processes; identifying and exploiting the enterprise's knowledge resources; identifying and developing the capability to use new tools; and reshaping the enterprise's physical infrastructure and network access.

- Paul Mercier, Manager, ICT Infrastructure and Operations
- Francois Allard, Systems and Automation Analyst, Computing and Communications Services
- Pierre De Gagné, Assistant Director, Physical Resources Service
- Ian McKay, Project Associate, Computing and Communications Services

Dalhousie University, Office of Sustainability

Dalhousie University and the Office of Sustainability recognize the crucial role they have to play in providing leadership in this area. The Office of Sustainability focuses on solutions that integrate and improve environment, economic, health and social conditions in campus operations. The Office works with campus, community, government and University partners.

- Rochelle Owen, Director of Sustainability
- Pat Power, Director, Networks and Systems
- Darrell Boutilier, Director of Operations, Facilities Management
- Matt McKinnon, Electrical Planning Manager, Facilities Management
- Lewis MacDonald, Mechanical Planning Manager, Facilities Management

University of Alberta, Office of the Vice-Provost (Information Technology)

The Office of the Vice-Provost (Information Technology) was established in July 2004 with the goal to lead the development, evolution and implementation of a long-range ICT plan for the University of Alberta. It also participates in and represents the University on major ICT initiatives undertaken by the University. The Office of the Vice-Provost (Information Technology) has 230 staff, which includes the Academic Information and Communication Technologies group.

- Jonathan Schaeffer, Vice-Provost and Associate Vice-President of Information Technology
- Mike Versteege, Energy Management Program Manager, Facilities and Operations Sustainability
- Jim Macdonald, Continuous Operations Team Leader, Academic Information and Communication Technologies

Data collection

One of the main objectives of this study is to assess the business case for greening University ICT assets by relocating or modifying data centres, leveraging CANARIE's very high-speed optical network. The business case must therefore consider numerous costs and revenues, such as the cost of constructing a data centre in a remote off-grid or central urban location, the cost of constructing a small power generating station, and the potential for revenues from the sale of GHG offsets.

To develop the business cases, the following steps were taken:

- A kick-off meeting and tour of data centres was conducted at each University to capture a high-level view of the existing ICT systems and facilities, and to discuss the project with participants and take note of their ideas and concerns.
- Basic schematic diagrams of each data centre were created, as well as a data collection template. Participants were asked to confirm the accuracy of the schematic diagrams and complete the data collection template.
- From the information gathered, the total power and space required to host identical ICT equipment at a new data centre facility were calculated, which formed the basis of the carbon footprint.
- The carbon footprint for each data centre was determined; these footprints were also aggregated.
- With the carbon footprint and other information, the volume of carbon credits and their value was assessed.
- Using industry standard metrics, expert guidelines and other assumptions, the cost to build and operate a data centre under each scenario was established.
- The cost to operate the existing data centre was compared with the cost to operate the data centre under each scenario.

To simplify the business case, the study assumes that except for the cost of electricity and the cost to operate and maintain the link to CANARIE, the operating cost of the existing University data centres is the same as the cost to operate the scenario data centre. In other words, the costs associated with facilities, mechanical systems, site management, security, system administration, network access, and so forth are considered to be the same under the status quo or one of the three scenarios.

Consequently, the main factors considered under the first scenario are the cost to power and cool the current University data centre, the cost to operate and maintain the generating station at the remote site, and the equivalent annualized cost to construct the new data centre, generating station and optical network. Under the second scenario, the cost to operate and maintain the generating station is replaced with the cost to purchase electricity from a low-emission grid source. Finally, the only major costs associated with the third scenario are the cost to power and cool the current University data centre and the cost to install and maintain the heat exchange equipment necessary to capture waste heat from the facility.

The next section of this report describes some general concepts in carbon footprinting, provides an overview of the data centre facilities investigated in this study, and describes the results of the carbon footprint, including a gap analysis.

Description of facilities

This section provides an overview of the main components of data centres and a brief description of the data centres of each University in this project.

Large data centres have a number of main infrastructure components that are consistent across installations. These include racks, servers, data storage devices, networking equipment, uninterruptible power supplies, backup power generators, power distribution units, and computer room cooling equipment.

Racks (sometimes called cabinets) are specialized shelving that hold the actual servers, data storage and networking devices, providing conditioned power and optimal cooling arrangements. Typically, data centres will use racks that are designed to house 42 standard height (1.75 inches) devices or units. These are designated as "42U" cabinets. The number of racks installed can be used as a representation of the computing capacity of the data centre, while the density or number of racks per square feet will influence the cooling requirements in a data centre. The density and the power consumption per rack (kW/rack) may be useful when comparing the efficiencies of similar data centres.

Servers are computing devices consisting of hardware and software that may be running a server operating system, dedicated to providing services such as printing, file storage, database storage, email applications, Web sites, and so forth.

Data storage devices form a dedicated system for centrally managing, storing and archiving data. These can include storage modules having controllers, disk drives, networking and management software configured as a Storage Area Network (SAN) or a Network Attached Storage (NAS) system. Archiving and backups are typically created using high-capacity magnetic tape drives and use robotic libraries and management servers to automatically manage all aspects of the transfer of data to and from the physical tapes.

Networking equipment includes routers, switches, hubs, gateways and firewalls, all serving to interconnect ICT systems to create a network within the University and to interconnect with the Internet and the CANARIE research network. In this study, telecommunications equipment (such as PBX, which is used to manage the University telephone system) is included in the networking equipment category.

Uninterruptible power supplies (UPSs) provide power conditioning and emergency power supply to data centre equipment. Because all critical equipment is continuously powered through the UPS, it allows for sufficient time for the data centre to undergo a managed shutdown or, in the case of larger data centres, perform continuous operations during the brief moments when the power source transitions between the electrical grid and the data centre's backup power generator. The UPSs often provide logging or real-time output of power in, power out and other key indicators useful in completing a carbon footprint.

Power distribution units (PDUs) are used to transform, provide circuit protection, and condition and distribute power across the data centre and within individual racks. Many PDUs provide metering of current flow and may have data logging and remote monitoring capabilities.

Computer room air conditioners (CRACs) are used in data centres to cool the ICT equipment (servers, data storage and networking devices), due to the power used by the ICT equipment, which is eventually converted to thermal energy. In order for the ICT equipment to function properly, it needs to be maintained at the appropriate temperature.

In addition to these main components, data centres can be configured in a variety of ways. For instance, in-row cooling (IRC) and hot aisle containment are increasingly popular approaches to organizing data centres, whereby heat rejected by the ICT equipment is contained in a "row," allowing for more efficient and effective cooling compared to common practice.

University of Ottawa

There are two main data centres on the University of Ottawa campus—one for administrative operations ("Vanier") and a second housing HPC systems used for research by the University staff and students ("Marion"). Participants from the University of Ottawa estimated that these two data centres make up over 60 per cent of the total computing power on campus.

The Vanier data centre is approximately 4,000 square feet and is equipped with raised floors and includes a staging area and operations centre. This data centre houses approximately 50 racks, three UPSs with a total of 130 kVA, and four CRAC units with a total cooling capacity of 80 tonnes. The

University is relocating the Vanier data centre to a new location in the basement of the new Social Sciences building; this relocation is expected to be completed in the first quarter of 2012. This new 3,000-square-foot data centre will house the administrative systems, and it is expected that the existing Vanier data centre will be decommissioned about six months after the relocation.

The Marion data centre is newer and significantly smaller at 800 square feet, housing 16 racks. The Marion data centre does not have a raised floor, but instead uses an IRC configuration that does not require the under-floor area for cold air circulation. This data centre features high-density servers powered by modular UPS and power distribution systems. The cooling is provided by proprietary modular cooling and air flow units integrated within the racks and connected to the University's central plant chilled water distribution system. The rejected heat is captured and used at the central plant to heat and cool other buildings on campus.

Dalhousie University

There are two data centres of significant size at the Dalhousie campus, with the largest data centre located on the main campus, in the basement of the Killam library. A second data centre is located at the Sexton campus of Dalhousie and is used mainly for data backup applications. Together, the data centres represent greater than 90 per cent of the servers on the campus (not including the School of Computer Science, which maintains a relatively large data centre for teaching purposes).

The Killam data centre is about 4,200 square feet, with a raised floor of about 12 to 18 inches, and is home to 70 racks. It also hosts the "GigaPoP" (the connection to CANARIE). Other, smaller networks to regional data centres (such as at research institutions, universities, and so forth) branch off from the GigaPoP. There are two UPSs at the Killam data centre (one old and one new) with a third to be installed in the near future. The UPSs feed all of the ICT equipment in the data centre, with an average combined power input of 250 kW. The five CRACs at the Killam data centre utilize an average of 311 kW.

The Sexton data centre is 792 square feet in size, located on the Sexton campus of Dalhousie University, with nine racks. One UPS and one CRAC provide power and cooling to the ICT equipment; the UPS output is rated at 30 kW, while the CRAC consumes 35 kW.

Dalhousie does not operate a central heat, power or cooling plant, although it has preliminary plans to construct one.

University of Alberta

There is one main data centre at the University of Alberta ("U of A") campus, the General Services Building data centre, with a smaller one located in downtown Edmonton in an office building managed by a third party (the Enterprise Square data centre). Together, these data centres are estimated to only represent between one-third and one-half of the total University ICT power consumption. Some administrative computing has been outsourced to IBM in Markham, with a backup stored in Montréal. The balance of ICT power consumption is a result of the operation of numerous other machine rooms at U of A, with dozens of (probably 30) ICT clusters on campus.

The General Services Building data centre is approximately 8,000 square feet, with 115 racks that house Voice over Internet Protocol, Research, and High Performance Computing. The data centre is powered through nine UPS units, totalling 409 kW average output. The data centre is cooled by nine individual CRAC units; a small amount of cooling is provided via a chilled water loop from the central plant at the University. The CRAC units have an input power rating of 389 kW.

Far less information is available to describe the Enterprise Square data centre, other than it is approximately 5,000 square feet, holds 50 racks using IRC, and is used mainly to host backup systems in case of a failure in the main data centre.

The U of A has a central co-generation plant (boilers, steam turbine), as well as a cooled water plant, which takes advantage of cold water sourced from the North Saskatchewan River.

Approach and scope

Following feedback collected during the kick-off meetings, it was determined that significant social, infrastructural and economic problems existed with relocating ICT assets to remote, renewably powered locations. To enhance the study, three possible carbon-credit generating scenarios were considered and compared to the baseline (i.e., status quo, business as usual). The first scenario represented the remote, zero-carbon data centre. In Scenario 2, the data centre was relocated, but to an urban location in a province with a low electrical grid emission factor and in a location where waste heat from the data centre could be captured and used. In the final scenario (Scenario 3), the data centre remains where it is currently located, but it is connected to the University's district heating systems. Table 1 summarizes the basic information for each scenario.

Table 1.

Summary of scenarios considered	Location	Power source	Carbon credits
Scenario 1: Remote location	Remote location in same province.	Small hydro power plant with diesel standby.	Displacement of grid electricity.
Scenario 2: Urban location	Urban location in a province with low electricity emissions, near CANARIE network and district heating system.	Low emission grid electricity.	Displacement of grid electricity with low-emission grid electricity; displacement of fossil fuel heating source with waste heat.
Scenario 3: Existing location	Current location.	Current power source.	Displacement of fossil fuel heating source with waste heat.

Each University typically has several data centres, some of which are full-fledged ICT operation centres having raised floors, industry standard power and cooling systems; others are simply rooms of various sizes accommodating assorted ICT equipment used by a specific group or department. To set a reasonable scope and limit the complexity of this study, we considered only the main ICT operation rooms designed and operated to host the University's mission-critical systems. In this study, all of the equipment in the selected data centres was targeted for relocation to the remote site. All other University computer systems found outside of the selected data centres were excluded from the study.

During the project kick-off, discussions were held with participants to review the design of the data collection template that would be used to capture the information needed to estimate the cost of relocating the data centre, along with the GHG generated by the operation of the data centre.

After review, a final template was designed to capture essential information to model the cost of building and operating a data centre and an electrical generating station capable of powering the remote site. The following information was obtained via data collection spreadsheet (see Appendix C):

- Size of the data centre in square feet;
- Number of cabinets occupying the data centre, classified by equipment type: server, disk storage, tape storage, networking;
- Average cost of each equipment type;
- Average number of systems per cabinet;

- Instantaneous power used by ICT equipment (determined via the UPS) or, if actual power use was not available, name plate power consumption or output;
- Instantaneous power used by data centre cooling equipment or, if actual power use was not available, name plate power consumption or output;
- System categorization: High Performance Computing, Email, E-Learning, Web portals, Enterprise applications, Database, Storage, and Other; and
- Staffing requirements to operate the data centre.

Size of data centre

Each University was requested to record the number of square feet within the University data centre, including areas used by the cabinets, CRAC, UPS, staging area and operation centre.

ICT cabinets

Each University was asked to take an inventory of the ICT cabinets in the data centre, recording the average size (number of units they could hold) and classifying them into one of the following four types:

- Server—a computer running an application, file service or database; hosting a Web site; an email server; etc.;
- Disk storage—a controller, network device or hard disk array integrated within a Storage Area Network or Network Attached Server;
- Tape storage—tape libraries and robotic systems, media storage racks, tape drives, backup systems, etc.; and
- Networking—telecoms, phone systems, networking switches, hubs and routers, etc.

The ICT manager was asked to estimate the average per cent filled (number of installed Units divided by the size of cabinets in Units) of the cabinets for each of the four types of systems.

Power usage

The site visit provided an opportunity to assess and document the electrical power distribution and cooling systems used in the data centres and to determine the methods available from which annual power consumption could be measured.

Following the visit to each University, a schematic diagram was created to document the power distribution, starting from the grid and the backup generators, to the data centre ICT equipment and cooling systems (see Appendix A). The schematics identified the available measurement points to be used for the data collection. Each drawing detailed the electrical source, backup generators, Automated Transfer Switches (ATSs), electrical power metres, UPSs, PDUs, and CRACs. The document was validated with the University ICT site manager and served as a reference to the person filling in the data collection spreadsheet.

Each University ICT manager was asked to provide power usage information for their ICT equipment and cooling systems using the identified measurement points. Unfortunately, none of the Universities conducted data logging of power consumption for their ICT equipment or cooling systems. Therefore, instantaneous power use (in kW) or, in the absence of any measurement, nameplate power consumption or output (in kW) were used as representative measures of power consumption.

Auxiliary power consumption was exclusively estimated based on information from the Uptime Institute (35 per cent of the power consumption of the ICT equipment). Therefore, total annual power consumption was determined using the equation below:

$$\begin{aligned} &\mathit{Annual\ Electricity\ Consumption}\ (kWh) \\ &\quad = [\mathit{IT\ Equipment}\ (kW) + \mathit{Cooling\ System}\ (kW) \\ &\quad + (\mathit{IT\ Equipment}\ x\ 0.35)]\ x\ 365(days)\ x\ 24\left(\frac{hours}{days}\right) \end{aligned}$$

System categorization

University data centres host a variety of software applications running on heterogeneous systems. The types of application can determine the actual power used by a server. For example, HPC systems typically run at maximum capacity for extended periods. These servers will often consume much more power than, for example, a Web server that is lightly loaded. For this reason, ICT managers were requested to classify their applications in the following categories: High Performance Computing, Email, E-Learning, Web portals, Enterprise applications, Database, Storage, and Other.

Staffing

Each University was asked to provide staffing requirements (number of people and shift per day) to manage the facilities, provide security and operate the data centre. This information was used to calculate the operating costs related to data centre personnel.

Carbon footprint

Carbon footprinting (also called a carbon or GHG inventory, GHG accounting, etc.) is a measurement of the GHG impact of a particular entity or process—in this case, the operation of a data centre over one year. The measurement of carbon typically includes the "Kyoto gases": carbon dioxide, methane, nitrous oxide and sulphur hexafluoride, as well as hydrofluorocarbons and perfluorocarbons. Due to the level of complexity intrinsic to monitoring carbon emissions, a range of "protocols" or rulebooks defining best practices in carbon accounting exist.

In this study, we followed the principles of ISO 14064-1, which provides guidance when completing a GHG inventory.[8] These principles (paraphrased below), in concert with necessary assumptions and simplifications, were employed to complete the carbon footprint (detailed in Appendix B) and carbon credit analysis (detailed in Appendix F) for each University and scenario.

- RELEVANT: Select the GHG sources, data and methodologies appropriate to the needs of the intended user.
- COMPLETE: Include all relevant GHG emissions.
- CONSISTENT: Enable meaningful comparison in GHG-related information.
- ACCURATE: Reduce bias and uncertainties as far as is practical.
- TRANSPARENT: Disclose sufficient and appropriate GHG-related information to allow intended users to make decisions with reasonable confidence.

More specific guidance is sometimes available for certain applications of GHG accounting; however, no well-established protocol exists specifically for data centres. Conceptually, within the general principles of ISO 14064-1, a variety of methods are available to quantify the GHG emissions of a data centre. These range widely along the spectra of measurement accuracy, ability to institute and cost to implement. For instance, ongoing, continuous direct measurement of electricity to each piece of equipment in the data centre would be ideal for the purposes of completing a carbon footprint; however, in practice, this level of data collection does not exist, due to the costs and complexity associated with such an undertaking.

For data centres considered in this study, ongoing direct measurement was not a common practice (nor would it be expected, based on common practice in the industry). Therefore, the most accurate method available for quantifying the amount of power consumed by the data centre was periodic measurement of instantaneous power consumption; when that was not available, nameplate readings were extrapolated to represent annual consumption.

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[8] ISO 14064-1:2006, "Greenhouse gases—Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals."

An additional challenge was that monitoring and data collection abilities between the University data centres in this study were not consistent—some data centres were able to take actual instantaneous readings, while others relied on the less accurate nameplate ratings. All of these factors make the consistent and accurate quantification of the carbon footprint of data centres challenging.

With the ISO 14064-1 principles in mind, a site visit to each University was conducted, including a tour of each data centre. Simplified data centre diagrams depicting energy flow, points of measurement and main data centre components were then generated. In parallel, a data collection template for each University was developed, based on its data collection capabilities, findings during the site tour and other correspondence. The template requested information on energy consumption, computing infrastructure and operational costs; a generic version may be found in Appendix C. Although the template attempted to capture information on the replacement of any refrigerant in the cooling system, only Dalhousie was able to provide this information and was not able to provide information on the type of refrigerant replaced. Certain types of refrigerant are considered potent GHGs; however, since the only information available was from one University and incomplete at that, this source was excluded from the quantification of the carbon footprint.

University personnel also provided invaluable input and feedback in interviews conducted during the site tours. Of course, each data centre (even within a given University) had a greater or lesser extent of monitoring capabilities, which is important to consider when the results are being discussed. Please see the subsection entitled Gap Analysis for a summary of methods used for each University. As previously mentioned, basic electrical and metering diagrams for each University are included in Appendix A.

Once all the power use information was collected via the templates and the annual electricity consumption for the University data centre(s) was determined, the carbon footprint could be quantified based on the following equation:

$$Carbon\ Footprint\ (tonnes\ CO2e) = Total\ Power\ Consumption\ (kWh)\ x\left(\frac{tonnes\ CO2e}{kWh}\right)$$

The unit of measure throughout this report is metric tonnes of carbon dioxide equivalent (tonnes CO_2e). This is the international unit that combines the differing impacts of all GHGs into a single unit, by multiplying each emitted GHG by its global warming potential (GWP). GWPs are used to compare the abilities of different GHGs to trap heat in the atmosphere, relative to that of carbon dioxide.

It is worth noting that in certain circumstances, cooling loads can be met via a chilled water loop, rather than by individual, electrically driven CRACs. In this study, Dalhousie exclusively used electrically driven CRAC, while the University of Alberta utilized chilled water loops along with CRAC in one data centre and the University of Ottawa used a chilled water loop exclusively for one data centre; however, insufficient metering equipment was installed in either case to reliably estimate the contribution of this cooling source to the carbon footprint. At the University of Alberta, cooling is achieved using cold water from the North Saskatchewan River, with the electricity required to operate the system derived from the University of Alberta's central plant; in Ottawa, a central chiller system utilizes electricity from Ontario's electric grid.

In the case of the University of Alberta, the contribution of the cooling from the chilled water loop was assumed to be negligible based on information received during the site visit and consultation with University ICT staff. In the case of the University of Ottawa, the cooling load was estimated based on the Uptime Institute standard estimate of 65 per cent of the total ICT equipment load, in the form of electric power obtained from Ontario's electrical grid.

Therefore, all sources of GHG emissions resulted from the consumption of electricity or the assumed consumption of electricity to power ICT equipment, auxiliary power and the cooling system. The carbon footprint was therefore determined by the emission factor associated with the electricity consumed to power the equipment in the data centres. In the cases of Dalhousie and the University of Ottawa, this electricity is obtained from their respective provincial grids—the grid emission factor was obtained for those provinces from Environment Canada.[9] The University of Alberta operates a co-generation plant generating a significant amount of the heat and power consumed on the campus; therefore, the provincial grid factor in Alberta was not applicable. Instead, staff at the University of Alberta provided an emission factor that was calculated in order to quantify the carbon footprint for the entire University.[10]

Emissions in this inventory were not identified as such, but could be classified into "scopes." Because all carbon emissions associated with the operation of a data centre in this study are associated with the consumption of electricity, all emissions would be categorized as indirect (Scope 2). The scopes are:

- Scope 1 (Direct emissions), e.g., Emissions from natural gas combustion on site at the data centre.

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[9] "National Inventory Report 1990–2008: Greenhouse gas sources and sinks in Canada," Annex 13 tables. The best available information is based on data from the 2008 calendar year and is still in draft form. These factors may therefore require revision in the future; however, these revisions are not expected to have a material impact on the carbon footprint or the potential for creating offsets.

[10] Email correspondence between C. Caners and M. Versteege from the University of Alberta, June 2010.

- Scope 2 (Indirect emissions associated with the consumption of electricity), e.g., Emissions resulting from electricity consumption or central chilled water at the data centre.
- Scope 3 (Other indirect emissions), e.g., Emissions related to waste disposal and business air travel arising from the operation of the data centre.

Summary of data collected and carbon footprint

Tables 2 and 3 below summarize the data collected via the data collection templates, as well as the aggregated carbon footprint for each University. Please note that the numbers presented in some tables may not add exactly due to rounding.

Table 2.

	University of Ottawa	Dalhousie University	University of Alberta
Average Power Consumption (kW)	676	724	934
Annual Power Consumption (kWh)	5,923,512	6,342,240	8,185,826
Emissions (t CO_2e)	1,007	5,010	5,288

Table 3.

Data centre specifications	University of Ottawa	Dalhousie University	University of Alberta
Number of racks	71	79	115
Rack density (sq. ft.)	68	64	70
Power per rack (W)	3,944	3,544	3,559
Power per sq. ft. (W)	141	144	117
Power for IT equipment (kW)	280	280	409
Power for cooling (kW)	298	346	382
Power for auxiliary use (kW)	98	98	143
Total Data Centre Power (kW)	676	724	934
Power Usage Effectiveness - PUE	2.4	2.6	2.3
Active area (sq. ft.)	4,800	5,024	8,000
Cost of electricity at University ($/kWh)	0.088	0.079	0.062

Gap analysis

As described previously in this study, the total power usage of a data centre is allocated to three categories: ICT equipment, cooling systems and auxiliary power. Ideally, each University would have extensive metering of each of those categories, with continuous data logging at an end-use equipment level. In the case of ICT equipment, continuous measurement would occur via a continuous data logging system built into the UPS (which would support all ICT equipment), cumulatively logging the total energy consumed for, at minimum, one year. Two of the three

Universities in the study initially believed that their systems had been capturing power data continuously for at least part of the system; however, this unfortunately proved not to be the case—it is important to note that the continuous collection of power information is not considered common practice at data centres; therefore, this level of data was not available for any of the three categories.

Power usage for the ICT equipment was therefore estimated by extrapolating instantaneous power use readings from the UPS or, if instantaneous measurement was not possible, the nameplate (input or output) rating of the UPS was used. In the case of the former method, administrators at each University took three instantaneous readings of power (input or output) over a week-long time frame. These values were then assumed to represent average power consumption values over the entire year. Although these readings are instantaneous and so are likely to change over the year (for instance, during the summer semester), ICT personnel at each University indicated that the power consumption did not vary significantly over time. In the case that instantaneous measurement was not possible, extrapolation of the nameplate ratings of the UPS was determined to be the most transparent, accurate and relevant method available to quantify the annual electricity consumption of the ICT equipment.

It is important to note that certain systems at Dalhousie considered non-critical by the ICT staff were not supported by UPS and, therefore, this power consumption was not captured in this analysis, as there was no reliable method for estimating the consumption; however, this is expected to account for a small percentage of the total power consumption at the data centre.

For the cooling systems, each CRAC would ideally be monitored on a continuous basis, similar to the ICT equipment, except CRACs are less likely to have that capability built in than UPS and are therefore even less likely to have direct monitoring of power consumption of any sort. In cases where instantaneous measurement was not available, cooling power consumption for each University was estimated based on the rated power consumption of each CRAC in the space. At the University of Alberta and University of Ottawa, chilled water from the central plants was also used for cooling; unfortunately, insufficient metering was in place to determine this effect directly. In the case of the University of Alberta, where the amount of cooling delivered by the central plant was described as minimal by University staff, no estimate was included; at the University of Ottawa, where one of the data centres was cooled exclusively by the central plant chilled water loop, an estimate of the cooling energy used was based on information from the Uptime Institute.[11]

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[11] According to the Uptime Model for TCO (Total Cost of Ownership) of data centres, the cooling system should consume 65 per cent of the total ICT equipment load.

No data centre auxiliary systems were metered directly at any of the Universities. As a result, electricity consumption for auxiliary systems was estimated based on the Uptime Institute standard estimate of 35 per cent of the ICT equipment power consumption.

It is very important to note the drawbacks resulting from the extrapolation of annual data centre power consumption from instantaneous or nameplate readings, since significant inaccuracies could occur. In the case of this study, most of the data centres investigated were running at or near their design capacity. However, data centre equipment (including UPS and CRAC) is typically loaded below the rated output for various reasons, such as to allow for data centre expansion or because the data centre operates in a redundant configuration, such that UPSs and CRACs serve only half of the data centre.

In cases where instantaneous measurements of ICT power were available, these measurements were only taken over a short time period (approximately one week) and therefore may not be representative of average power consumption throughout the year. ICT personnel at each University suggested that the IT equipment load did not change substantially over a given year, however.

In the absence of continuously logged power consumption data for ICT equipment, CRAC and auxiliary systems, and given that in some cases, only nameplate ratings of power consumption were available, the most reasonable approach to estimating annual power consumption was used; however, the assumption is that the instantaneous measurements and nameplate information may not hold true at all times and may lead to inaccuracies in this study.

Finally, each University was asked to provide information on the amount and type of refrigerant replaced during the 2009 calendar year; depending on the exact type, refrigerants may be classified as GHGs. Only Dalhousie was able to provide information on the volume of coolant replaced, however, with no indication as to the type of coolant. Therefore, this potential source of GHG emissions was left out of the carbon footprint. Table 4 provides a summary of how electricity consumption data were collected under each main category, by University.

Table 4.

Data Collection	University of Ottawa	Dalhousie University	University of Alberta
ICT equipment	1, 2	1,2	1
Cooling systems	2	1	2
Auxiliary power	3	3	3

1=Annual electricity consumption based on extrapolation of instantaneous direct measurement of power consumption.

2=Annual electricity consumption based on extrapolation of nameplate rated power consumption.

3=Estimation based on Uptime Institute model.[12]

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[12] J. Koomey, K. G. Brill, W. P. Turner, J. R. Stanley and B. Taylor, September 2007, "A simple model for determining true total cost of ownership for data centers," Santa Fe, NM: The Uptime Institute, available at www.uptimeinstitute.org.

Analysis and results

This section of the report presents the results of the economic analysis, in two main sections. First, the Relocation Analysis section describes some of the basic assumptions and the approach taken in order to estimate the costs associated with the prospective University data centre scenarios considered in this study. Second, the volume of carbon credits available and the resulting potential revenue from their sale are considered in the Summary of Carbon Credits and Revenue, for each scenario.

Relocation analysis

Size of data centre

We have assumed that the prospective data centre represented by Scenario 1, 2 or 3 would require the same area as the existing data centre to house the ICT and cooling equipment. This assumption may not always hold true, however, since some Universities have a sparsely populated data centre (i.e., they have space to expand), while others are already limited by the size of their computer room and would in fact need to replace equipment with higher density systems or expand the physical size of the data centre. Having simply used the current square feet of the University data centre as the size of the prospective data centre, future needs for expansion were not taken into consideration in the study.

ICT cabinets

The University ICT managers recorded the average size (number of Units they can hold) of the cabinets and classified them into one of following equipment types: Server; Disk storage; Tape storage; and Networking. The ICT managers estimated the average per cent filled (number of installed Units divided by the size of cabinets in Units) of the cabinets for each of the four types of systems. Although not as accurate as a complete system inventory, this approach provides a good approximation of the cost and the power requirements of a data centre.

To establish a base price for the servers, the study used the IBM model x-3550 M2,[13] 1U system priced at $4,983. We also assumed a cost of $3,000 to set up, power, network, install a full set of servers and test each cabinet. This number has been validated by University personnel on the data collection spreadsheet.

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[13] IBM Canada x-3550 M2, 1U rack mount system, IBM System x3550 M2 Express Model (Product: 7946E2U) with 2 Intel Xeon Processor E5530 4C 2.40GHz and 3-year onsite repair 24x7 4 Hour Response (Product: 43X3679).

Power usage

The power usage of the data centre was allocated to three categories:

- ICT Equipment: comprises all information systems, typically but not always measured at the output of the UPS;
- Cooling system: power used by the cooling systems within the data centre (CRAC units); and
- Auxiliary: power used for lighting, building HVAC, electrical outlets for facilities, power loss by UPS, CRAC and other equipment, etc.

Ideally, the total power usage would be measured and recorded by a central electrical power metre on the main power grid feed, which would supply the data centre exclusively. The reality for Universities, however, is that the data centre is often housed in one of the campus buildings, making it difficult to isolate the total power usage. For example, chilled water may be shared across campus, or electrical power may be distributed across buildings without isolated metering. Due to similar metering limitations, the auxiliary power consumed by each data centre was estimated based on information from the Uptime Institute,[14] which sets auxiliary power consumption at 35 per cent of that of the ICT equipment. For this study, the total power consumed by each data centre is the sum of the ICT equipment, cooling system and auxiliary power consumption, as shown below:

$$Total\ Power\ (kWh) = ICTEquipment\ (kWh) +\ Cooling\ System\ (kWh) +\ Auxiliary(kWh)$$

One method that is commonly used to determine the efficiency of a data centre is the Power Usage Effectiveness (PUE), calculated as the total power divided by the ICT equipment power. Typically, existing computer rooms have a PUE ranging from 2.0 to 2.5, which indicates that the total power used by the data centre is often more than twice the power used by the ICT equipment. With the advent of green ICT, some of the new data centre designs are targeting a PUE of less than 1.5, which alone will significantly reduce energy consumption and GHG emissions (assuming a constant ICT load). Lower—more efficient—PUE are often achieved by making more use of "free-cooling" (using outside air to cool the data centre) by having more efficient building designs, by reuse of heat generated by the data centre, and by designing more efficient equipment and cabinet layouts for better cooling.

This study assumes a power factor of 1.0 across all equipment; thus we are assuming that the apparent AC power, measured in kilovolt-amperes (kVA), is equal to the real power, measured in

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[14] J. Koomey, K. G. Brill, W. P. Turner, J. R. Stanley and B. Taylor, September 2007, "A simple model for determining true total cost of ownership for data centers," Santa Fe, NM: The Uptime Institute, available at www.uptimeinstitute.org.

kilowatts (kW). This assumption was made to simplify the calculation of power used in cases where only the nameplate power consumption of data centre equipment was available.

High-speed network

An important technical assumption made by this study is that a very high-speed network with a minimum speed of 10 GB/s would interconnect the University and the prospective data centre. This network would allow staff, students and systems full access to the remote resources without experiencing latency problems caused by lower bandwidth or lower-speed networks. Under Scenario 3, this connection is assumed to already exist, as the existing data centre is maintained; however, this connection would be required under Scenarios 1 and 2.

The high-throughput network would allow ICT administrators to seamlessly (i.e., without impact on systems or users) transfer systems and applications to the prospective site with little or no noticeable changes to performance and reliability. The network would allow the relocation of software applications and, more importantly, provide a channel with enough bandwidth to use the prospective site as a data storage location. To ensure privacy, security and reliability, the envisioned network would be private to the University (not connected over the Internet).

Since CANARIE's high-speed optical network already interconnects all Universities across Canada, it is an ideal platform in the context of the technical and security requirements stated above. The study thus assumes that the high-speed network interconnecting the University to the prospective data centres in Scenario 1 and Scenario 2 will be an extension of CANARIE.

Virtualization technology

Universities have acquired a wide range of computing and storage platforms allowing them to provide support for the full breadth of applications that are required to run the University business, scientific, research, educational and academic systems.

Many of the specialized "legacy" applications require specific servers that run operating systems that are no longer current. Although these older or very specific systems are often covered under paid support services sold by the equipment manufacture, it is often not possible to acquire an identical system for relocation.

A possible solution is to use virtualization technology, which can create a virtual operating environment mimicking a specific platform, allowing ICT managers to move legacy applications on newer hardware platforms. This enabling technology can also be used to host many virtual servers in one physical machine, reducing the cost of hardware, improving system utilization and reducing the total power consumption.

Setup cost for relocation

This study assumes that existing University data centre equipment will not be moved to the prospective sites in Scenario 1 and Scenario 2. Instead, the new data centre will progressively be populated with newly purchased equipment, as required, to:

- replace existing systems (which will be decommissioned at the University site); and
- add new capabilities required by University applications.

This assumption eliminates the cost of tearing down, transporting and assembling existing University systems. This approach will allow for a progressive move toward the new data centre as the equipment advances to the end of its life cycle, and eliminates service interruptions due to relocation of ICT hardware. On average, the ICT managers assume that data centre equipment has a lifetime ranging from three to five years, at which time the equipment is renewed or decommissioned. Exceptions to this occur for systems having very specific technical requirements, such as mainframes and ICT equipment required to support legacy applications (for example, an older tape backup system kept to restore legacy media).

Prospective data centre costs

Data centre tier levels

The tier level of a data centre defines the level of redundancy and backup paths for power, cooling and other critical mechanical and electrical systems supporting the ICT equipment. The Uptime Institute's Tier Classifications defines four levels (Tier I to Tier IV) representing categories of site infrastructure topology that lead to increased system reliability, availability and serviceability.

Tier I: provides a dedicated space, UPS to filter power and provide momentary power during outages, dedicated cooling and an engine power generator to protect during grid power outages. Tier I is generally appropriate for small businesses to support internal systems and for Internet companies without quality of service commitments.

Tier II: includes redundant critical power and cooling capacity components for an increased safety margin in case of infrastructure failure due to malfunction or planned maintenance. The redundant components are typically an extra UPS module, cooling units, chillers, pumps and engine generators. Tier II is appropriate for companies that do not depend on real-time delivery of products or services for their revenue stream. Many institutional and educational organizations select this tier.

Tier III: this tier adds redundant delivery paths for power and cooling to the critical components to support the ICT equipment during maintenance, and also to allow each system or component that supports ICT operations to be taken offline for scheduled maintenance without impacting the ICT environment. This level of redundancy is extended to the mechanical plant, engine generator, power sources for cooling equipment, pumps, and so forth. Companies selecting this tier level have high-availability requirements (24 x 7) for ongoing business or have identified a significant cost of disruption of an unplanned event.

Tier IV: adds to Tier III the concept of fault tolerance to the infrastructure. The effect of a failure is considered on other site infrastructure systems and components. This tier is for businesses based on E-commerce or financial settlement processes, large global companies delivering services 24 x 365, for whom the cost of disruption is profound in terms of economic and market share impact.

Because the tier level directly dictates the performance level and the major infrastructure components, it has a direct influence on the cost of building a data centre. Typical University data centres operate at the Tier I or Tier II level, and some may have a mix of infrastructure redundancy to provide for specific system availability based on requirements and budget.

For Scenario 1 and Scenario 2, the Tier II-level data centre building costs were used to determine the cost per kW to construct the site. No tier level was explicitly applied to Scenario 3 because the existing data centre is not relocated under that scenario. Tier III costs are approximately twice that of Tier II.

Cost of site

This section outlines the costs associated with the purchase of land accompanying the relocation of the data centres. Because it is outside of the scope of this study to find and select a site for the relocated prospective data centre envisioned under Scenarios 1 and 2, the following assumptions were used in the study.

Scenario 1:

- The site is located in a remote northern community 100 kilometres from the University;
- The data centre does not have access to the provincial electrical grid;
- A river with sufficient flow is available to operate turbines providing the required electrical energy year round;
- The data centre is 500 metres from the generating station;
- The cost of acquiring the land and acquiring permits is assumed to be $10 per square foot at a remote site; and

- The University is connected to the data centre using CANARIE's very high-speed optical Research and Education network (R&E).

Scenario 2:

- The site is located in a centralized, urban area;
- The data centre has access to a low-emission intensity provincial electrical grid, such as in British Columbia, Manitoba or Québec;
- The data centre is located in close proximity to a district heating system that can readily interconnect with the data centre;
- The cost of acquiring the land and permits is assumed to be $38 per square foot;[15] and
- The University is connected to the data centre using CANARIE's very high-speed optical Research and Education network (R&E).

Construction cost

The cost of constructing a relocated data centre under Scenario 1 and Scenario 2 is based on research from the Uptime Institute.[16] Since the Uptime Institute's cost model is presented in $US and based on the *Engineering News-Record* indexes of 2007 construction cost, all values were converted to Canadian currency and adjusted for inflation to reflect the increase of construction and components.[17]

The Uptime Institute has established that there are three primary construction cost drivers for data centres:

- Power and cooling capacity or density (total kW or kW/rack);
- Tiers of functionality, which define the concurrent maintainability or fault tolerance of the site; and
- Size of the computer room floor (number of square feet or number of racks).

The Uptime Institute estimates that it costs $331 per square foot of active ICT floor space and $209 for every square foot of spare (expansion) area to construct a data centre. The cost of the active area space is independent of tier level and includes a raised floor, building shell and core (incidental office

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[15] Based on an informal survey of commercial real estate prices in Montréal.

[16] K. Brill and W. P. Turner, 2008, "Cost model: Dollars per kW plus dollars per square foot of computer floor," Santa Fe, NM: The Uptime Institute.

[17] A conversion rate of US$1 = CAD$1.07 was used (based on the July 2007 rate) and an additional 3.94 per cent was added to the cost to account for inflation between 2007 and 2010. Based on Bank of Canada historical currency exchange rates and inflation rates, www.bankofcanada.ca.

space for facilities, lobby, restrooms, conference room, interior partitions, loading dock, storage area, etc.), normal interior finishes, lighting, building HVAC for makeup air, fire detection and pre-action sprinklers, and other space items that are not related to kW or functionality tier level cost.

In addition to the raw space cost mentioned above, Uptime has established the cost to convert the space to a functioning computer room. Basically, this is the cost of purchasing and setting up the power distribution and cooling systems for the ICT equipment based on the tier level functionality. This includes the underlying and redundant mechanical and electrical infrastructure capacity (measured, in kW, for UPS and required cooling), as well as the distribution equipment needed to support the tier level. These components are comprised of the utility switchgear, power distribution backbone, engine generators for backup, UPS, batteries, PDU, chillers, pumping, piping, cooling units, fuel system and space to hold all equipment.

Accordingly, Uptime has established the following costs per kW (converted to 2010 CAD$), outlined in Table 5 below, for converting a building into a functioning data centre. For this study, the Tier II cost was assumed and multiplied by the ICT equipment power to establish the cost to convert the space to a functioning data centre.

Table 5.

Functionality level	Cost per kW (2010 $)
Tier I	12,670
Tier II	13,772
Tier III	24,341
Tier IV	27,544

To establish the total cost to construct the data centre, we have added to the floor space and data centre conversion capital cost the following items:

Scenario 1:

- Cost of land and permits for the data centre was assumed to be $10 per square foot—this represents the cost per square foot to purchase the land, pay for environmental and local impact assessments, and the required building and operating permits. An additional 20 per cent was added to the data centre size for parking area and other utility space;[18]
- Racking up and cabling of ICT systems—this is the cost of setting up the ICT equipment in the cabinets. It includes the cost of cabling, networking and testing each unit. A cost of $3,000 per cabinet was used;

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[18] Estimate based on professional judgment.

- Cost to migrate and configure software—ICT specialists will be required to plan, implement and test the migration of applications and data to new systems. The study assumes 1.5 full-time employees (FTE) over the project life; and,
- To establish the link from the remote site to CANARIE, we have assumed a cost of $500,000, based on guidance from CANARIE personnel.

Scenario 2:

- In an urban setting, the cost of land and permits for the data centre was assumed to be $38 per square foot—this represents the cost per square foot to purchase the land/building;
- Racking up and cabling of ICT systems—this is the cost of setting up the ICT equipment in the cabinets. It includes the cost of cabling, networking and testing each unit. A cost of $3,000 per cabinet was used;
- Cost to migrate and configure software—ICT specialists will be required to plan, implement and test the migration of applications and data to new systems. The study assumes 1.5 FTE over the project life; and,
- To establish the link from the data centre to CANARIE, we have assumed a cost of $26,000, based on guidance from CANARIE personnel.

Operating and maintenance cost

Apart from the power to run the data centre and the cost of maintaining the link to CANARIE, the study makes the assumption that the cost of operating the remote data centre is the same as the University data centre. In other words, the cost associated with facilities, land, taxes, mechanical, HVAC, electrical systems, site management, security, system administration, network access, and so forth are considered to be the same at all sites, existing and prospective.

The cost of electricity for the University data centres is calculated by making the assumption that data centre power consumption is constant, multiplying the instantaneous total power (ICT equipment, cooling system, auxiliary) by the number of hours per year (to obtain kWh per year) and by the cost of electricity per kWh (to obtain total cost). The cost of electricity for each site is based on information from a Hydro-Québec report;[19] electricity prices for the Universities are based on the large power consumer category of 5,000 kW.

Because power is generated and not purchased at the remote site, there is no cost of electricity for the remote off-grid data centre under Scenario 1. Under Scenario 2, the cost of electricity is based on the rates provided in the Hydro-Québec study referenced above.

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[19] The report can be found at www.hydroQuébec.com/publications/en/comparison_prices.

Electrical generating station

This section of the report reviews the assumptions and parameters used to estimate the capital and operating costs associated with the construction and operation of a small hydroelectric generating station for the remotely located data centre in Scenario 1. These costs do not apply to Scenario 2 or 3.

Construction cost

This study assumes that the generating station will produce enough electricity for the current data centre power requirements (ICT, cooling and auxiliary), without expansion. To ensure that enough power could be generated year round, even if water levels were lower than average, the capacity of the generating station was established as the total data centre power multiplied by two, rounded up to the nearest megawatt.

The construction cost is based on a small hydro station and is calculated with an all-in multiplier (cost per MW), based on ICF International's Integrated Planning Model. ICF's small hydro assumptions are based on the Canada Centre for Mineral and Energy Technology (CANMET) International Small Hydro Atlas[20] as of August 2007. The International Small Hydro Atlas cost information is specific to each province and is based on data collected over the last 20 years. The site-specific cost information is based on established formulae and individual studies incorporated into the database. In order to represent the cost and potential in each province on an aggregate basis in the model, four cost classes were developed (very low, low, medium, and high cost) by ICF International. They reflect the weighted average cost of all potential sites in each designated class. In this study, we have used the "medium" cost model for each province and have increased the cost by 6.23 per cent to reflect the inflation rate from 2007 to 2010 (based on historical rates from the Bank of Canada).

We assume that the purchase of land, permits, environmental and local impact assessments, and project management costs are incorporated into the construction cost model of the generating station.

Transmission line cost

The study assumes that the data centre under Scenario 1 will be located 500 metres from the generating station; therefore the cost of establishing a transmission line is included. The unit cost per kilometre (km) for a 115 kV double circuit transmission line on a tubular steel pole is CAD$1,478,000. This cost assumes construction on a flat forested land and includes an additional

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[20] See www.small-hydro.com.

factor (1.5 x) accounting for a distance of less than 10 miles (17 kilometres). The unit cost includes the engineering and construction costs only. Environmental, permitting and right of way acquisition costs are not included. The costs for a 60/70 kV line are the same as for the 115 kV line, due to same standards used for new installation.

Unit Cost per km = USD$1,250,000/mile x distance factor x mile/km x CAD/USD x Inflation
Unit Cost per km = 1,250,000 x 1.5 X 0.6214 x 1.2456 x 101.84% = CAD$1,478,000/km. [21]

The purchase of land, permits, environmental and local impact assessments, and project management costs are not built into the cost of the power line; therefore, the actual cost would likely be slightly higher.

Operating and maintenance cost

The yearly cost to operate and maintain the generating station is a function of the generating capacity. The operating and maintenance cost per kW per year is based on ICF International's Integrated Planning Model for a small hydro project located in the province under study. Added to this cost are the yearly water rights and land taxes, which together are estimated to represent approximately 10 per cent of the annual operating expenses.

Emission intensity of new generating station

As described previously, each remote data centre envisioned under Scenario 1 is assumed to be powered via a small, run-of-the-river hydroelectric installation. The emission intensity associated with this type of installation is assumed to be zero, as no fossil fuels are consumed directly to generate electrical energy.[22]

Summary of relocation costs

Electricity used to power and cool the ICT equipment is one of the major operating costs of a data centre. As can be seen in Table 6, in Scenarios 1 and 2 the operating and maintenance cost of the relocated data centre is less than the cost of electricity for the existing (status quo) data centre. But when the annualized capital cost of constructing the remote data centre (Scenario 1) is taken into consideration, the cost of operating and financing the remote site can be far more in total than the status quo. Similarly, the cost of operating and financing the relocated data centre described by Scenario 2 is significantly greater (in the hundreds of thousands of dollars annually) than the status

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[21] Source: Peter Ng, February 2009, Pacific Gas & Electric Company, www.caiso.com/2360/23609c2864470.pdf.

[22] While some fossil fuels will undoubtedly be consumed during maintenance procedures and travel to the hydroelectric station, these emissions are estimated to be extremely small and difficult to assess accurately with any level of certainty. These emission sources have therefore not been included in this analysis.

quo. For Scenario 3, the annual operating cost increases slightly due to the added cost for the maintenance of the heat exchanger system. For more detail on these analyses, please refer to Appendix E.

Table 6.

Status Quo	**University of Ottawa**	**Dalhousie University**	**University of Alberta**
Annual operating cost	$520,590	$500,805	$508,711
Capital cost	-	-	-
Scenario 1	**University of Ottawa**	**Dalhousie University**	**University of Alberta**
Annual operating cost	$173,037	$187,643	$212,802
Capital cost	$19,721,592	$16,580,179	$19,263,064
Annualized cost of capital	$1,437,827	$1,238,284	$1,486,264
Scenario 2	**University of Ottawa**	**Dalhousie University**	**University of Alberta**
Annual operating cost	$290,971	$311,540	$402,100
Capital cost	$6,164,114	$6,270,665	$9,256,134
Annualized cost of capital	$556,347	$565,964	$835,420
Scenario 3	**University of Ottawa**	**Dalhousie University**	**University of Alberta**
Annual operating cost	$525,590	$505,805	$513,711
Capital cost	$150,000	$150,000	$150,000
Annualized cost of capital	$13,538	$13,538	$13,538

Summary of carbon credits and revenue

This section provides an overview of carbon markets in North America, explains how the number of carbon credits available were estimated, and then, based on that analysis, estimates the potential revenue available from the sale of those credits.

Overview of North American carbon markets

The purpose of this section is to summarize the current state of climate change policy in four jurisdictions: Canada (federal level of government); the province of Ontario; the United States (federal level of government); and regional policy programs (namely, the Western Climate Initiative). Each set of policies will be summarized along several core design elements (e.g., description of program, use of targets, compliance mechanisms). The purpose of this information is to provide readers with context and perspective on CANARIE's broader strategic concept of leveraging revenues from carbon credits to green ICT activities.

Canadian federal government

The climate change policy environment in Canada has developed rapidly over the past decade. Numerous strategies have been put forward by both Liberal and Conservative-led governments ("Action Plan 2000," "Climate Change Plan for Canada," the "Green Shift," etc.). The latest policy iteration, "Turning the Corner" (TTC), was proposed in April 2007. Unlike the Kerry-Lieberman bill in the United States (discussed below), TTC proposes the use of intensity-based targets rather than absolute reduction targets. This is a core differentiator in the two countries' climate change strategies. Canada's stated goal is to reduce national GHG emissions to 17 per cent below 2005 levels by 2020.[23] Since Canada's national GHG emissions in 2005 were 731 Mt CO_2e, this implies that Canada's emissions in 2020 cannot exceed 607 Mt CO_2e. TTC would impose intensity-based targets on companies operating in the following sectors: electricity generation, oil and gas, pulp and paper, iron and steel, smelting and refining, potash, lime, cement, chemicals, and fertilizers. In addition to its use of intensity-based targets, the program is distinguished by its use of a Technology Fund. The main implication of the Technology Fund is that it essentially sets a price ceiling for companies in covered sectors of $15 per tCO_2e for the first three years of the compliance period.[24]

Ontario

Ontario's climate change policy is driven largely by its membership in the Western Climate Initiative (WCI). The province is in the process of developing a cap-and-trade system as part of its commitment to the WCI. Bill 185, introduced in the Ontario legislature in May 2009, and the Green Energy Act (GEA), passed by the Ontario government in December 2009, collectively provide the foundation for the province's cap-and-trade program. As of July 2010, no system has been launched. Ontario signed a memorandum of understanding with the province of Québec in June 2008 to set up an interprovincial cap-and-trade system. According to the latest government announcement, the start date of the system is scheduled for 1 January 2012. The province has set GHG reductions targets of 6 per cent below the 1990 level by 2014, 15 per cent below the 1990 level by 2020 and 80 per cent below the 1990 level by 2050. Ontario continues to work toward its goal of phasing out all coal-fired power plants by the end of 2014.

United States federal government: The Kerry–Lieberman bill

The state of climate change policy in the United States is characterized by a distinct sense of uncertainty. In the last three years, no less than three separate climate change plans have been passed by the US House of Representatives (the Kerry–Boxer bill, the Waxman–Markey bill and the Kerry–Lieberman bill). At this time (August 2010), the US Senate has not passed any of these bills. In this

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[23] This goal, which matches the commitment of the United States, was announced by the Minister of Environment, Mr. Jim Prentice, at the UN Climate Change Conference (COP-15) held in Copenhagen in December 2009.

[24] Contributions are scaled up to $20 tCO_2e in 2013 and thereafter increase in line with Canada's nominal GDP growth.

paper we focus on the Kerry–Lieberman (K–L) bill, as it is the most recent legislation. The K–L bill, released on 12 May 2010, aims to introduce a cap-and-trade system in the United States covering electric utilities (by 2013) and industry (by 2016). As in past climate change policies, the bill includes a variety of consumer rebates, support programs for state-level renewable energy development and incentives for energy investments. Capped sectors would face an emission reduction target of 17 per cent below 2005 levels by 2020 and 80 per cent below 2005 levels by 2050. One element that distinguishes the K–L bill from previous efforts is that it would introduce a price collar of between $12 to $25 per tonne, increasing at 3 per cent + Consumer Price Index (CPI), with a ceiling of 5 per cent + CPI.

Regional: Western Climate Initiative (WCI)

Launched in 2007 by the states of Arizona, California, New Mexico, Oregon and Washington, the WCI provides for the creation of a regional cap-and-trade system to support an absolute regional GHG reduction target of 15 per cent below 2005 levels by 2020 (based on individual members' commitments). Since WCI's formation in 2007, Montana and Utah have joined the regime, as well as the Canadian provinces of British Columbia, Manitoba, Ontario, and Québec. Beginning in 2012, the program would impose targets on companies based in the following sectors: electricity generation and imports, large industrial and commercial combustion sources, and industrial process emissions. By 2015, the following sectors would also face targets: residential, commercial and industrial fuel combustion, and transportation fuel combustion.

Comparison of key carbon market design elements

The four climate change policies under review share a number of similarities and some fundamental differences. The key discrepancies among the programs are explored below.

Targets

The K–L bill uses a 2005 baseline and proposes an absolute reduction in US GHG emissions of 17 per cent by 2020 and 80 per cent by 2050. The WCI, which also uses a 2005 baseline, proposes a 15 per cent decline in regional emissions by 2020. K–L's targets are thus more aggressive, broader and extend further into the future than those used by the WCI. The TTC program seeks to reduce Canada's GHG emissions to 17 per cent below 2005 levels by 2020 and by 60 to70 per cent below 2005 levels by 2050. The targets used in K–L and TTC represent different challenges. Meeting K–L would result in US emissions falling slightly below 1990 levels, while the TTC target would not quite return Canadian emissions to that level. On the other hand, the Canadian target implies a greater challenge, because emissions are projected to rise by approximately 40 per cent from 1990 levels in

Canada,[25] while US emissions were otherwise projected to remain relatively flat to 2020.[26] Ontario's targets are unusual in the sense that they are based on a 1990 baseline. Since Ontario's (and Canada's) emissions in 1990 were considerably lower than their emissions in 2005, the use of a 1990 baseline implies greater reduction requirements. Ontario has a stated reduction target of 6 per cent below the 1990 level by 2014, 15 per cent below the 1990 level by 2020 and 80 per cent below the 1990 level by 2050.

Scope

K–L can be expected to affect a broader array of companies than the WCI, TTC or Ontario's climate change plan. As it currently stands, the K–L bill would cover companies in most industrial sectors of the US economy, including electrical generation/utilities, petroleum producers and importers and natural gas local distributions companies. The bill covers emissions from the approximately 7,500 major stationary sources that emit greater than 25,000 tonnes per year of GHG emission. WCI covers emissions in sectors including electricity generation, industrial and commercial facilities and residential, commercial and industrial fuel combustion. In both schemes, all six GHGs are regulated; K–L also regulates nitrogen trifluoride. TTC also regulates all six GHGs but is distinguished by its treatment of fixed process emissions, which are not covered under the regulations. This particular feature of TTC means that sectors whose fixed process emissions represent a relatively high proportion of their overall emissions face much less regulatory exposure than they would under K–L or WCI. Sectors in Canada that may benefit from this feature include the cement and lime industries. From a carbon market perspective, a consequence of excluding fixed process emissions is that any accompanying domestic offset market will be narrower and less liquid than would otherwise be the case. Other things being equal, a narrower market scope tends to imply higher allowance prices.

Compliance options

The compliance options that companies can avail themselves of under K–L, TTC and WCI are broadly similar. Under both regimes, companies can use domestic/international offsets, allowances and internal abatement to meet reduction requirements. K–L allows unlimited borrowing from the following year's allowances without any penalty. K–L also stipulates that a maximum of 2 billion tonnes per year of offsets can be used, of which 75 per cent must come from domestic sources. Assuming a shortage of domestic offsets, the bill imposes a ceiling of international offsets of 1 billion tonnes per year. The United States and international offset markets could experience a shortage relative to aggregate global demand if targets specified in K–L are upheld by the Senate review. Like other markets where supply is constrained and demand is strong, the effect is likely to be an increase in offset prices compared to historical averages. Under WCI, no more than 49 per

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[25] Per the TTC projection.

[26] Annual Energy Outlook, 2009.

cent of total emission reductions from 2012–2020 can be met from offsets. As mentioned earlier, TTC is distinguished by its use of technology fund contributions. In addition, companies in certain sectors can also qualify for pre-certified investments under the technology fund.[27]

Distribution of allowances

K–L would distribute emission allowances beginning in 2013 and annually through 2029 to residential, commercial and industrial consumers to compensate for increases in energy bills. The distribution of allowances under WCI will proceed once the allowance budget has been established by each WCI partner. A minimum of 10 per cent of each partner's 2012 allowance budget must be auctioned, increasing to 25 per cent by 2020. Currently, an undetermined portion of the revenue that each WCI partner receives from auctioning must be dedicated to a series of public purposes.[28] It is stated that the method of allowance allocation under TTC will be determined during the regulatory development process.

Complementary measures

Complementary measures are an important part of any comprehensive climate change strategy. One of the key benefits for policy-makers of including aggressive complementary measures is that it reduces the pressure on domestic cap-and-trade systems to deliver large emission reductions. Both K–L and WCI include a wide range of complementary measures. K–L contains numerous incentives for energy efficiency, smart grids and the development of alternative energy sources. WCI specifies a Renewable Portfolio Standard (RPS), a renewable fuel standard and clean car standards equivalent to California's Pavley Rules I and II. One of the major weaknesses of TTC is that it contains relatively few complementary measures and the programs it does include are generally not well defined. For example, TTC assumes action on the part of the provinces which, in some cases, has not been agreed upon. Moreover, TTC indicates that the electrical generation sector will reduce sectoral emissions by 25 Mt but it does not specify how this reduction target will be achieved.

Individual summaries of each carbon market system discussed above are included in Appendix G.

Quantification

For this exercise, the quantity of carbon credits available to each University were estimated based on the difference between the GHG emissions associated with the operation of the data centre as currently located (the "baseline"), and that of the relocated remote data centre powered by renewable electricity (the "project")—see the equation below. As discussed previously, GHG

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[27] These sectors are oil sands, electricity generation, chemicals, fertilizers and petroleum refining.

[28] The sectors are energy efficiency; carbon capture and storage research; emissions reductions in uncapped sectors (e.g., agriculture); and human adaptation to climate change.

emissions from the data centres are effectively associated with Scope 2 emissions only[29]—in this case, the consumption of electricity by the ICT equipment, cooling systems and auxiliary equipment. It was assumed that under the project scenario, the relocated data centre would have the same electrical load and distribution between ICT equipment, cooling system and auxiliary power as in the baseline scenario. In this way, the number of carbon credits available will be overestimated rather than underestimated, representing a best-case scenario regarding revenue from the sale of carbon credits.

Emission Reductions = Baseline Emissions – Project Emissions

In addition to analyzing the case for a remotely located, renewably powered data centre (Scenario 1), we have also considered two other scenarios, as described previously. In Scenario 2, the data centre is moved to a province with a low-emissions grid, such as British Columbia, Manitoba or Québec, in an urban location where waste heat could be used, and with access to CANARIE. Then, in Scenario 3, the data centre is not moved from its current location; however, heat exchange equipment is installed to capture waste heat, thereby generating offsets by displacing the use of a heat source driven by fossil fuel (in this case, natural gas). Each case is analyzed through the balance of this document.

Scenario 1

GHG emissions associated with electrical power are dependent upon the source of the electricity being used. In the case of the baseline, this is the emission factor of the electricity grid in the province in which the University is situated. In cases where the University (such as the University of Alberta) operates a central co-generation plant (a plant that generates both heat and electrical power), the emission intensity of that system was factored into the calculation, based on the percentage of the total annual electricity consumption that is supplied by the co-generation plant.[30] Total electricity consumption (ICT equipment, cooling system, auxiliary equipment) is determined by taking instantaneous power consumption (measured and/or rated), determining the total kWh, and multiplying that by the appropriate emission factor. Because the data centre is remote in this scenario, it is assumed that there is no readily available use for the waste heat from the data centre. Were the waste heat from the data centre to be captured, it could displace other, fossil fuel derived heat, generating credits—this is considered instead under Scenarios 2 and 3.

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[29] Although the University of Ottawa and the University of Alberta both operate centralized chilled water loops, the University of Ottawa's system is completely fueled by grid-sourced electricity. In the case of the University of Alberta, a very small portion of the cooling requirements for the General Services Building data centre is provided by the chilled water loop; however, insufficient data were available to measure this amount, which was assumed to be negligible in the final calculation.

[30] Based on engineering calculations, University of Alberta staff estimated this emission factor to be 646 g/kWh consumed at the University; therefore, that value was used for this study.

Under the project condition—the remote, renewably powered, data centre—electricity is assumed to be supplied by a run-of-the-river hydroelectric generating station. Because the hydroelectricity is generated without the use of fossil fuels, the GHG emissions associated with this electricity source are nil. In order to account for variations in seasonal power output and to allow for the data centre to grow, the net power output of the plant is assumed to be rounded up to the nearest megawatt of the existing data centre demand. The volume of credits available is therefore based on the assumed power output of the entire plant—not just the power consumed by the data centre, as the balance of electricity generated is assumed to displace grid-generated electricity.[31]

The remote data centre will need to have access to a secondary source of electricity in order to allow its uninterrupted use, however. In this exercise, we have assumed that this electricity is supplied by an on-site standby diesel generator set. The utilization factor of the hydroelectric plant is assumed to be 90 per cent;[32] therefore, the diesel generator set runs for 10 per cent of the year. Emissions from this use of the diesel generator set make up the project emissions, calculated using an emission factor and the quantity of electricity to be supplied.[33]

Scenario 2

Under this scenario, the baseline condition is identical to that of Scenario 1, plus one factor—the amount of emissions from fossil fuel heat generation that capturing the waste heat from the data centre would replace. Because under Scenario 2, the data centre is assumed to have moved to an urban location in a province with a low electricity grids factor, the displacement of fossil fuel derived heat by the waste heat from the data centre is assumed to occur for the quantification of carbon credits. This value is derived based on the assumption that 75 per cent of the cooling load supplied can be captured as waste heat due to losses assumed in the system.[34]

As mentioned previously, the project scenario assumes that instead of a remote, renewably powered facility, the relocated data centre is located in Montréal, Québec, which has a very low grid emission factor. The emissions under the project condition are therefore the Québec emission factor multiplied by the total amount of electricity required annually.

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[31] Although carbon credits are assumed to be generated based on the total power generated by the power plant under Scenario 1, no costs have been assumed for the transmission lines or interconnects, which would be necessary were the end user of that electricity located in a different location than the data centre and power plant.

[32] The utilization factor for a small hydroelectric installation is based on expert opinion.

[33] The heating values of natural gas (under Scenarios 2 and 3, it is assumed that heat from a natural gas source is displaced via the capture and use of the waste heat from the data centre) and heating oil (for the standby generator assumed under Scenario 1) were obtained from *The Climate Registry, General Reporting Protocol*, Table 12.3: "Canadian default factors for calculating CO_2 emissions from combustion of natural gas, petroleum products and biomass"; the GHG emission factors for natural gas and heating oil were based on information from "National Inventory Report 1990–2006: Greenhouse gas sources and sinks in Canada,," Annex 12: Table A12–1 and Table A12–2.

[34] This efficiency is based on expert opinion.

Scenario 3

In this final scenario, emissions under the baseline condition are a result of the consumption of electricity from the provincial grid as well as fossil fuel derived heat generation—in this study, represented by the combustion of natural gas.

In this scenario, however, the project case is the baseline because the data centre remains in the same location and does not utilize renewable electricity—so there are no carbon credits for the use of renewable energy. Instead, all credits are generated by the displacement of fossil fuel derived heat (natural gas) with waste heat captured from the data centre. The difference between the baseline and project conditions in this case is that the waste heat from the data centre is now being used for a beneficial purpose and displacing the consumption of natural gas.

Revenue

Carbon credits generate revenue through their sale, and prices in North America range widely, depending on a number of factors. It is therefore important to understand this context when investigating the generation of carbon credits. Of course, when trying to maximize revenue from the sale of carbon credits, it is most beneficial to generate the maximum number of credits possible.

There are two general types of markets where carbon credits can be generated, registered and sold: the compliance and the voluntary markets. The former is a market dictated and regulated by a government entity (for instance, the federal Canadian government or the Government of Alberta), while the latter can range from completely unregulated with little oversight to a rigorously regulated system that supplies carbon credits to entities that are keen to reduce their GHG emissions. For instance, a company may wish to offset its carbon footprint and become "carbon neutral," or an individual may wish to offset the emissions associated with his or her personal air travel.

Prices for carbon credits vary both between and within these markets. In general, the retail price of compliance carbon credits is higher than that of voluntary carbon credits, because compliance credits are generally more difficult to obtain. This is because the methodologies by which credits may be generated (the rules of the exchange, or "protocols") are typically more stringent and because the demand for credits is present as a result of the regulated nature of the market. Currently, prices for compliance credits range from under \$15 per tonne of CO_2e under the Alberta Offset System[35] to between \$15 and \$23 per tonne of CO_2e on the European Climate Exchange.[36]

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[35] Alberta Environment, http://environment.alberta.ca/01855.html. Because trading of offset credits are private transactions between buyers and sellers, exact prices paid remain unknown; however, because entities that require compliance credits may purchase them from the Alberta government for \$15 per tonne, the price for Alberta offset credits is known to be less than \$15—likely between \$8 to \$14, depending on the type of project and other factors.

[36] European Climate Exchange, www.ecx.eu/General/CER-price-curve-shifting-as-new-ECX-contracts-boost-transparency, accessed June 2010.

Once again, because sales for some of the main North American voluntary markets like the Voluntary Carbon Standard (VCS) or California's Climate Action Reserve (CAR) occur over the counter, average prices are not publicly available; however, voluntary credits typically retail at a lower price than their regulated counterparts. On the Chicago Climate Exchange (CCX)[37] prices are publicly available and typically retail for less than $1 per tonne of CO_2e. For the VCS and CAR, where prices are known only to buyers and sellers, prices range from $10 to $12 per tonne of CO_2e. This is due in part to the myriad existing rules (or lack thereof), which generate credits of varying quality. Furthermore, because (by definition) emission levels are not capped by regulation, demand is much softer and is more susceptible to economic downturn and buyer opinion.

Furthermore, compliance and voluntary systems may allow only certain project "types"—for instance, landfill gas is currently an acceptable project type on CAR; however, energy efficiency projects cannot currently generate credits under that system. Even within specific voluntary and compliance markets alike, credits resulting from certain project types can be more desirable to buyers (due to their perceived rigour, optics and/or risk[38]) and can therefore command a higher price. Ultimately, the price that a given carbon credit can demand is contingent upon a range of factors: the specific system, the demand for offsets, and the type of project, under a given registry.

For this study, we have used the results from ICF International's Canadian Carbon Markets Study, which evaluates demand and supply for offsets in the context of a federally regulated Canadian cap-and-trade emissions scheme. We have also assumed a project crediting period of eight years, which is consistent with the Alberta Offset System[39] and similar to the Clean Development Mechanism.[40] Although a federally regulated Canadian cap-and-trade emissions scheme is far from reality at this time, this price scenario will likely represent the best case situation for the Universities in terms of price per tonne of CO_2e that can be achieved by a carbon market. Prices applied from the Canadian Carbon Markets Study rise steadily, from approximately $19 in 2013 to $52 per tonne of CO_2e in 2020.

Certain costs are associated with bringing carbon credits to the market. First, information supporting a claim to carbon credits must be compiled, addressing issues such as methodology, ownership,

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[37] Chicago Climate Exchange, www.chicagoclimatex.com, accessed June 2010.

[38] Risk can manifest itself differently in voluntary and compliance markets, but both depend mainly on the risk that the credits are found to be of insufficient quality after purchase. In the voluntary system, this can lead to negative publicity for the buyer; in a compliance setting, financial penalties for the buyer may occur if the credits are not guaranteed by the administrator of the system, such as in the Alberta market.

[39] This is based on Alberta Environment's *Offset Project Credit Guidance* document, which indicates that the credit duration period for offset projects under the Specified Gas Emitters Regulation in that province is eight years; see http://environment.gov.ab.ca/info/library/7915.pdf.

[40] Under the Clean Development Mechanism, the initial crediting period is seven or ten years. It is possible to renew the former period, at most twice, while the latter cannot be renewed. See http://cdmrulebook.org/310, accessed July 2010.

additionality and monitoring. These documents are often compiled by external consultants; this study assumes a one-time cost of $20,000 for this effort (one-half for internal administration, with the balance allocated to an external consultant). Second, any transparent claim to carbon credits will require verification by an independent third party. These verifiers review the claim and issue a letter of assurance, similar to financial accounting. Verification costs are incurred each time credits are claimed; typically, this occurs on an annual basis. Therefore, this study assumes a cost of $15,000 annually ($5,000 for internal administration, with the balance allocated to an independent third-party verifier). Finally, this study assumes that any carbon credits would be posted on a public registry; in this study, the registration of credits is assumed to have a one-time cost of $200, plus a fee of 5 cents per tonne registered and $500 annually.[41]

Table 7 presents the average net annual carbon credit revenue over the eight-year project life, which is the average gross revenue from the sale of carbon credits (which changes year to year with a changing price of carbon), minus the costs associated with the administration of the credits (such as documentation and registration).

Table 7.

Status Quo	University of Ottawa	Dalhousie University	University of Alberta
Average net annual carbon credit revenue	-	-	-
Scenario 1	**University of Ottawa**	**Dalhousie University**	**University of Alberta**
Average net annual carbon credit revenue	$60,125	$405,161	$320,642
Scenario 2	**University of Ottawa**	**Dalhousie University**	**University of Alberta**
Average net annual carbon credit revenue	$42,035	$187,486	$246,414
Scenario 3	**University of Ottawa**	**Dalhousie University**	**University of Alberta**
Average net annual carbon credit revenue	$6,742	$10,243	$59,455

Results

This analysis found that none of the Universities under any of the three scenarios considered in this study would be able to economically take advantage of carbon credits to finance the required infrastructure upgrades and/or changes. The average net annual total project revenues (which include all capital costs, operating costs, carbon credit costs, and carbon credit revenues and net present value [NPV] for each of the Universities under each of the three scenarios) are presented in Table 8.[42]

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[41] These registration fees are estimated based on the cost to register credits on the Canadian Standards Association CleanProjects Registry, conservatively using the volume of credits available under Scenario 1 for each University.

[42] The book value of the assets at the end of the crediting period (eight years) was added to the revenue in the final year in order to calculate the NPV of the project. Depreciation rates of 7 per cent, 30 per cent and 6 per cent were applied to

Table 8.

Scenario 1	University of Ottawa	Dalhousie University	University of Alberta
Average net annual total project revenue	$(281,298)	$(281,785)	$(281,666)
Net present value	$(8,535,093)	$(6,968,567)	$(8,448,132)
Scenario 2	**University of Ottawa**	**Dalhousie University**	**University of Alberta**
Average net annual total project revenue	$(185,801)	$(186,288)	$(186,169)
Net present value	$(3,401,831)	$(2,682,716)	$(3,616,477)
Scenario 3	**University of Ottawa**	**Dalhousie University**	**University of Alberta**
Average net annual total project revenue	$(13,135)	$(13,622)	$(13,503)
Net present value	$(95,128)	$(76,374)	$189,579

Scenario 1

The analysis of Scenario 1 results in a negative NPV for all Universities: $(8,535,093) for Ottawa, $(6,968,567) for Dalhousie and $(8,448,132) for Alberta, making an unattractive investment proposition. Expenses consist of operation and maintenance of a small hydroelectric generating station, water rights and land taxes. Annually, these incremental operating expenses were approximately $300,000 less than the status quo (the cost of obtaining electricity at the existing facility), not including the cost of capital, which was estimated to be $19,721,592, $16,580,179 and $19,263,064 for Ottawa, Dalhousie and Alberta, respectively. The average net annual carbon credit revenues from the sale of carbon credits were $60,125 (Ottawa), $405,161 (Dalhousie) and $320,642 (Alberta), with the large range due to the ability of the University data centres to generate carbon credits in their respective provinces due to differences in the electrical grid emission intensity. Volumes of credits generated under this scenario span an order of magnitude from 2,207 tonnes of CO_2e per year for Ottawa, up to 9,563 tonnes of CO_2e per year for Alberta.

Scenario 2

Under this scenario, the NPV analysis is more favourable, but still results in negative values for all Universities studied, from $(3,401,831) for Ottawa, to $(2,682,716) for Dalhousie and $(3,616,477)

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the power generating station, ICT assets and buildings, respectively, based on expert judgment and the Canadian Revenue Agency (www.cra-arc.gc.ca/tx/bsnss/tpcs/slprtnr/rprtng/cptl/dprcbl-eng.html). In the case of Scenario 3, the heat exchanger system was assumed to have no book value upon the completion of the project, as it is not a piece of infrastructure that could easily be separated and sold. The book value of the heat exchange equipment is included in Scenario 2 because that equipment is a part of the entire building, which would be assumed to be sold as one asset. Also relevant to the NPV analysis, discount rates were assumed to be higher under "riskier" Scenarios; hence, Scenario 1 has the largest discount rate (12.05 per cent), followed in turn by Scenario 2 (10.05 per cent) and Scenario 3 (8.05 per cent). The rates are based on informal discussions with experts in the field and on Bank of Canada rates V122487 (Government of Canada average yield over 10 years; 06/2007–04/2010 = 4.05 per cent).

for Alberta. Operating expenses increased between Scenario 1 and Scenario 2 because, under this scenario, all electricity must be purchased at the new location from the provincial grid (assumed to be that of Québec). However, Scenario 2 does better economically overall, because the cost of building, operating and maintaining a small hydroelectric facility is not required and because the volume of carbon credits (and therefore revenues) is greater under Scenario 2 than under Scenario 1. The volume of credits increases because incremental credits are generated via the use of waste heat from the data centre and the displacement of natural gas-derived heat as a result. Under the first scenario, these credits were not available due to the location of the data centre and the resulting waste heat in a remote location, where no use for the waste heat is readily available. The volume of credits generated is 1,697 tonnes of CO_2e annually for Ottawa, 5,812 for Dalhousie and 7,470 for Alberta, with associated average net carbon credit revenues of $42,035 for Ottawa, $187,486 for Dalhousie and $246,414 for Alberta.

Scenario 3

The NPV analysis for this scenario resulted in a positive outcome for the University of Alberta, but not for the other two Universities. The NPV ranged from $(95,128) for Ottawa, to $(76,374) for Dalhousie and $189,579 for Alberta—the only positive NPV result of the study. Expenses were estimated to be the least for this final scenario, as the only major expenses consisted of the purchase of electricity to operate the data centre (which is identical to the status quo costs, because the data centre is not relocated under this scenario) and the installation of a basic heat recovery system. Capital costs were estimated to be $150,000 for each University, while net revenues from the sale of carbon credits were $6,742 for Ottawa, $10,243 for Dalhousie and $59,455 for Alberta. This scenario is the most economically attractive of the three considered in this study.

Summary

Ultimately, the potential revenue generated from carbon credits is insufficient to offset the capital and operating cost of moving a University data centre to a remote, renewably powered location. Using relatively aggressive assumptions (such that the potential revenue from carbon credits is likely overestimated rather than underestimated), revenue from the sale of carbon credits ranges from a low of $6,742 (Scenario 3, University of Ottawa) to a high of $405,161 (Scenario 1, Dalhousie University) annually.

The University of Alberta under Scenario 3 saw the only positive NPV analysis (however, as outlined in the discussion, further capital expenditures over and above the cost of heat exchange equipment may be required to realize this project). The number of carbon credits that can be generated via the use of renewable energy is dependent upon emission factor for the electricity under the baseline condition, compared to the emission factor for electricity under the project condition. Although the University of Alberta operates a co-generation plant with a lower electricity intensity than that of Dalhousie (which sources its electricity exclusively from the provincial electricity grid), more credits were generated for the University of Alberta due to a larger data centre with greater electricity consumption.

Although only one of the scenarios was profitable from an NPV standpoint, a number of factors came to light during the site visits and discussions with University staff and other experts that may make the relocation of data centres advantageous to Universities, in spite of the economic disadvantages. In particular, a centralized data centre for Universities and other CANARIE stakeholders in an urban location with a low-emission intensity electrical grid would likely have numerous economic, environmental and infrastructure benefits. This concept and its advantages are examined in greater detail in the discussion section of this report.

Discussion

As is evident from the results section, the economics of relocating University data centres to remote, renewably powered locations are not compelling. It should be noted, however, that the cost of the data centre construction is probably estimated on the high side because of the Uptime Model. Actual cost may be lower for the following reasons:

- The data centre may implement a lower, less expensive Tier level than assumed in the study;
- Construction costs can vary significantly across Canada and may be lower than Uptime estimates, which are based on United States averages;
- A new data centre would use the space in the optimum manner, through higher density and use of virtualization, thereby reducing capital construction and equipment costs;
- Universities may choose to implement different levels of redundancy for different categories of systems (e.g., high performance computing, or HPC, systems do not always require backup UPS); and
- Universities could opt to co-locate in a commercial data centre, avoiding or reducing the costs associated with construction of the data centre.

At the same time, there are a number of things that could make the scenario worse economically. For instance, determining an accurate discount rate for each scenario is a challenging process; it is likely that these are underestimated, rather than overestimated. Another variable that is highly uncertain and may be overestimated is the expected over-the-counter price that carbon credits can fetch. Currently, these prices are based on models predicated upon the expected federal Canadian system; however, with policy now uncertain, so too are these price estimates.

There are also a number of other issues concerning this analysis and the context of relocating University data centres.

First, a University may be reluctant to relinquish ownership of its emission reductions, as semi-public institutions, University students, staff and faculty are often more interested in reducing the carbon footprint associated with the institution and would therefore wish to retire any credits themselves. Second, the future of carbon markets is very uncertain. The Canadian government has indicated they will delay any legislation concerning climate change because they wish to align their policy with that of the United States. The timeline for finalizing climate legislation in the United States is far from certain, however; it may be several years until a nationwide cap-and-trade system is established, if at all.[43] In fact, the only carbon system currently operating in Canada is Alberta's, established via the Specified Gas Emitters Regulation, where prices are effectively capped at $15 per tonne of CO_2e. Were a regulated system for credits to remain in the planning stages, it is likely that prices for carbon credits would remain low, with a potentially fragmented market and uncertain demand. Third, if a federal carbon market were to become established, it is unclear whether or not electricity displacement projects would be eligible to generate carbon offsets under that system's rules. The applicable project type (renewable energy, energy efficiency or fossil fuel displacement) may be ineligible due to double-counting or non-additionality.[44]

Universities are administratively complex, with numerous departments and funding sources—individual professors frequently operate independent laboratories, with dedicated ICT equipment. Faculty members often purchase their own equipment and wish to operate it independently. This legacy of independent systems can represent a significant barrier to the relocation of data centres to remote locations, depending on the individual University. For instance, centralized data centres at the University of Alberta represent an estimated one-third of the total ICT power consumption on the campus, while this ratio was estimated to be greater than one-half for both Dalhousie and the University of Ottawa. In addition, the faculty, students and staff who operate these independent ICT systems are often used to physically accessing the equipment and are hesitant to relinquish this ability. As a result, the identification and centralization of ICT equipment at each University represents an additional cost and barrier to remote relocation.

Another concern is the security of the equipment, data and infrastructure were a University data centre be moved to a remote location. Once again, due to the breadth and depth of the research conducted at these Universities, confidential, proprietary or secret information may be stored at data centres. Therefore, contingencies to address certain systems now included within the existing centralized data centres at the University may be required.

An issue related to this is the redundancy of the system—both in terms of access to data, and system operation. First, it was determined that any remote data centre will need two independent connections to CANARIE, such that if one network was disrupted, the data centre could still be accessed via the redundant network. This would increase the cost of establishing the remote data

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[43] The Canadian government, for instance, released guidance documents for a proposed cap-and-trade system in 2008; however, no major policy movement has occurred since that time. Establishing a cap-and-trade system would likely take several years, as the regulations are developed and as they are implemented.

[44] Under a cap-and-trade system, certain "regulated" sectors will be required to reduce their emissions (i.e., sectors under the cap); this would likely include the power generation sector. Because power generation companies would already be required to comply with a cap on their emissions, carbon credits that reduce electricity consumption or generate renewable power may be considered non-additional (the reductions would have occurred anyway) or double-counting (if carbon credits were generated by a capped sector). Therefore, under such a situation, a mechanism called a "set-aside" would be required in order for renewable energy or electrical efficiency to be accepted. As the complexity of a particular project type's suitability increases, so the likelihood of its acceptability decreases.

centre and may be technically difficult to achieve, depending on the location of the remote facility and accessibility to CANARIE.

As discussed previously, the remote data centres are assumed to be powered by a small run-of-the-river hydroelectric plant. The power generation capacity from these types of facilities is highly dependent upon the season, precipitation, snow melt and other meteorological factors. Although an emergency backup generator is assumed in the cost of the data centre, this backup system is not designed for extended operations, only for intermittent backup during grid power failures. To allow for regular maintenance and to ensure data centre operations during extended service operations of the electrical generating plant, a secondary power source will be a necessity, via connection to the grid or to a secondary generation system powered by natural gas, diesel or other renewables. This would, of course, come with a significant cost.

Finally, appropriate and adequate measurement and verification is a critical element required in order to generate carbon credits of value. Although this level of measurement could very likely be implemented exclusively under the project condition, were historic information to be needed, the level of measurement and verification that exists in the University data centre would almost certainly be insufficient. It is important to stress that this is not unexpected or divergent from the current best practice in data centres.

More specific discussion pertaining to the results of the three scenarios is included below.

Scenario 1

Under this scenario, the data centre is relocated to a remote location and is powered by a small hydroelectric installation. The economics of this approach are quite unfavourable; however, the expenses are heavily dependent upon the cost of generating renewable energy (installation, operation and maintenance) and the cost associated with relocating the data centre.

Electricity can be transported over relatively large distances; the data centre does not necessarily have to be relocated to a remote location in order to take advantage of renewable energy or to generate carbon credits. Therefore, the financial and logistical burden of relocating the data centre does not have to occur, and the data centre can still be powered exclusively by renewable energy.

In certain jurisdictions, carbon credits may not be the most attractive means of generating revenue. For instance, in Ontario, the Feed-In-Tariff (FIT) provides pricing longevity at relatively high rates for electricity; however, for that price and certainty, participants in the FIT program must sign over the right to any carbon credits associated with the electricity generated. Since the FIT provides a guaranteed revenue stream, and due to the volatility of the carbon market, the FIT program may be a far more attractive source of revenue for this scenario.

An additional concern is the up time and reliability of any off-grid installation—for this study, an off-grid location was assumed to be the most economic approach; however, a connection to the main electrical grid for backup purposes is a possibility as well. Should the renewable facility remain offline for any significant length of time, operating the standby diesel generators would be a significant cost.

Furthermore, credits are assumed to be generated based on the total power generated by the power plant and not solely on the electricity consumed by the data centre under this scenario; however, this relies on the unlikely scenario that a use for that electricity is near the data centre and power plant, since no connection to the provincial grid is available. Therefore, carbon credits under this scenario are likely overestimated, rather than underestimated.

Finally, the data centre will very likely require a redundant connection to CANARIE to meet Tier II specifications, which has not been included in this analysis and would add significant capital cost (if assumed to have an identical cost to the first connection, $500,000).

Scenario 2

Taking advantage of the variety of emission factors associated with provincial electricity grids, this scenario considers relocating the data centres to an urban location where waste heat from the data centre could be put to good use, in a province with a very low grid electricity emission factor. In this way, carbon credits can also be generated via the displacement of fossil fuel with waste heat, and the capital expenditure that would be required to establish a renewable energy facility would not be incurred.

While the revenues are still far below the incremental expense associated primarily with relocating the data centre, annual revenues in the hundreds of thousands of dollars are possible, which would have a significant impact on the overall economics of the project.

The concept of the community cloud is based on Scenario 2—where emissions resulting from the concentrated ICT infrastructure can be mitigated most easily, and where waste heat from such a data centre can be easily utilized.

Scenario 3

This scenario is expected to generate carbon credits with significantly less economic investment and with less administrative burden. This is because under this scenario, the only change to the status quo is the capture of waste heat from the data centre itself.

It is important to note a couple of assumptions that are influential in the outcome of the analysis. First, the installation of the heat exchange system is assumed to cost $150,000, which will vary depending on a number of factors, including accessibility to a central heat distribution system and the configuration of the data centre. For instance, Dalhousie does not currently operate a centralized heat or cooling system (although they are currently considering such a system), while Ottawa and Alberta do. Additionally, the assumed annual maintenance cost of $5,000 may be absorbed by routine and existing maintenance procedures.

Second, related to the first assumption, the data centre is assumed to be in an advantageous configuration for the recovery of waste heat, such as containment by in-row cooling (IRC). IRC is not common amongst older-vintage data centre cooling systems, however—of the six data centres investigated in this study, only one operated in an IRC configuration (located at Ottawa U). The only University with a positive NPV analysis was the University of Alberta, under this scenario—and although U of A does have a district heating system, its data centre is not in an IRC configuration and it is very likely that, in a more detailed engineering study of this option, the cost of reconfiguring the data centre would result in a negative NPV analysis. If the University invested in a new or reconfigured data centre, however, the capture of waste heat might be an economically attractive proposition.

Alternative approach

Based on the analysis above, it is clear that there are a number of barriers, financial and otherwise, associated with each scenario considered, especially Scenario 1. During the course of this investigation, another alternative to greening data centres became apparent. Under this alternative approach, one or more co-located data centres, shared by a number of Universities via CANARIE (ideally, using a cloud configuration) would be established. These clouds would be designed to mitigate the environmental impact of their operations—resulting in the creation of a "green community cloud" data centre.

Cloud computing concept

Cloud computing consists of network (usually Internet) delivered computing resources (hardware, software, applications) provided on-demand to users and computing devices. Cloud computing users typically avoid capital expenditures by renting usage from the cloud providers, paying only for resources that they use. Cloud computing infrastructure usually provides three layers of metered resources and services over a network. Most cloud service providers offer redundant, on-demand access to services based on user proximity. These types of on-demand services are categorized as follows:

Infrastructure as a Service: IaaS is the delivery of computer infrastructure as a service. Instead of buying servers, storage, operating software, data centre space or network equipment, clients purchase necessary resources as a fully outsourced service. The service is metered, allowing for short- or long-term usage of resources. For example, a virtual server can be rented on-demand having specific configurations for CPU, storage and memory. IaaS allows organizations to very quickly provision a new service at lower cost because of the on-demand infrastructure model.

Platform as a Service: PaaS is layered on top of IaaS. It facilitates the deployment of applications without the cost and complexity of buying and managing numerous hardware and software layers. Services are provisioned as an integrated solution; no software downloads or installations are necessary to realize all of the computing capabilities. For example, a fully configured and operational server running a standard operating system can be delivered with this service.

Software as a Service: SaaS typically involves pre-built business applications, tools and workflows—for example, Human Resource Management, Sales Force Automation, Business Intelligence, email, word processing, and so forth. This type of service allows users to instantly access their applications through standard Internet enabled devices. Some Universities are already making use of SaaS through tools such as Google mail. SaaS is an interesting service layer because it allows ICT managers to deploy new services without having to purchase, install and configure hardware, networking, servers and operating systems. The SaaS supplier will usually provide a simple setup and configuration tool and ensure that all data backup and recovery procedures and tools are operational and available.

CANARIE green community cloud alternative

A green community cloud ("community cloud") configuration would allow each University to set up and manage proprietary systems for their own use, while gaining access to significant shared resources. Combining more modest financial resources from a number of Universities would allow for the deployment of very powerful platforms provisioned as virtual servers. This configuration has the potential to reduce the cost to purchase and deploy the hardware, provide flexibility to Universities in supplying their computing needs, reduce operating costs via techniques such as virtualization, and reduce the impact of data centre operations on the environment through green power and waste heat recovery.

Connected via CANARIE, access to the community cloud from the Universities would be seamless in terms of performance and service access. CANARIE would allow the use of specific networking services that could be used to limit access only to authorized and authenticated users, offering reliable, extremely high-speed connections to standard cloud computing service layers.

Scope of service

In the near term, the most likely and useful service that a community cloud could provide to Universities is a combination of partitioned (private University) areas and shared IT systems such as storage, HPC and servers.

In particular, HPC is a very specialized, capital intensive and operationally expensive area. Anecdotal evidence collected during this study suggests that HPC equipment may sit idle for long periods when the original need that the equipment was originally intended to serve has passed. If HPC resources could be shared effectively between Universities, the result would be that capital expenditures on HPC equipment would decrease, and utilization of existing HPC equipment would increase, while maintaining immediate access to pooled HPC resources.

Another particular potential area that could benefit from a community cloud concept is storage. Because CANARIE already links together leading Canadian research institutions, a community cloud could host a data repository, where research data are stored and catalogued for use by other researchers on CANARIE. Where proprietary, confidential or sensitive data are involved, this data could be securely stored, providing a backup service for green cloud users.

Greening the cloud

Each cloud would ideally be located (and therefore powered by electrical grids) in provinces with low electricity grid emission intensity (such as Manitoba, British Columbia or Québec), or powered via renewable sources of electricity—although, as demonstrated in the analysis of Scenario 1, the latter is unlikely to be financially attractive.

A community cloud that consolidates some University ICT activities would also provide an opportunity to take advantage of waste heat. With more ICT resources operated in a convenient configuration (e.g., IRC) and location (e.g., in close proximity to a district heating system), the use of some fossil fuels could likely be displaced with the waste heat from the community cloud.

CANARIE is well positioned to lead the establishment of a community cloud, because it operates the most advanced optical network in the country and has an existing stakeholder base from which to draw users. The financing and operation of the project could potentially involve commercial partners; alternatively or in addition to this, user institutions could provide operational funding for the facility. If desired, the facility could also be split in a combination of co-location and cloud resources to allow institutions to have physically separate facilities to set up highly proprietary systems.

Organization

There are infinite approaches available that could be used to establish and operate a community cloud. For instance, participating Universities could provide a portion of their capital ICT budgets to CANARIE, which could administer and leverage those funds to construct one or several community clouds. Annual fees based on use could also be employed to fund the operation of the cloud.

Alternatively, CANARIE and a private entity could enter into a public–private partnership, with the private company supplying and operating the community cloud, with access to CANARIE. Operating costs could then be supplied via fees paid by the Universities on a flat rate or per-use basis.

Green community cloud construction cost

The cost of constructing a community cloud can be estimated using the combined requirements of the three Universities investigated in this study, totalling 265 racks consuming an average of 3,658 watts each. Assuming a density of 35 square feet per rack, this would require a building having approximately 10,000 square feet of IT equipment space.

Using the unit cost and formulas created for Scenario 2 of this study, it would cost approximately $21,000,000 to construct and set up the community cloud in an urban location such as Montréal. If we convert this expenditure into an annualized cost, and add the cost of electricity required to operate the data centre, the estimated annual operating cost of the data centre would be approximately $2,900,000. As noted in the Analysis and Results section, apart from the power to run the data centre and the cost to maintain the link to CANARIE, the study does not take into consideration the cost associated with facilities, land, taxes, mechanical, HVAC, electrical systems, site management, security, system administration, network access, and so forth. These expenses are already in the University budget and would be similar at the co-location site.

Commercial co-location cost

To provide a comparative benchmark, we have researched the cost to move all three University data centres to a commercial site, one possible location being in British Columbia and the other in Québec. The cost of operating the data centre equipment at a community cloud site is based on pricing provided by commercial service providers located in British Columbia and Québec. These data centres are powered by renewable energy (hydroelectricity) and all are connected to CANARIE.

The pricing does not reflect any reductions that would normally be available during a tender for service, nor does it account for volume discounts that would normally be factored in for a sizeable purchase.

The commercial co-location cost includes the racks and space for all University systems, power and cooling, building security, and basic system support. The British Columbia site offers near-Tier III redundancy for networking, cooling and electrical, while the Québec site offers equivalent Tier II redundancy.

In the commercial scenario, the start-up cost to set up the IT systems ranges from $945,000 to $1,224,250. The yearly cost to operate the systems ranges from $2,932,500 to $4,235,927 per year. The pricing includes all facilities, land, taxes, mechanical, HVAC, electrical, security and site management expenses. For a summary of this analysis, see Appendix D.

Comparable community cloud costs

A comparable project to this alternative community cloud approach is the joint project between McGill University (CLUMEQ) and the University of California, San Diego (SDSC Centre) to design an ultra-efficient data centre for high performance computing applications. The study proposes to build a shared data centre in Québec to host HPC systems used for research and to locate backup systems for University disaster recovery programs. The planned efficient building design will allow for a very cost-effective data centre (theoretical PUE of less than 1.2) by making the maximum use of water and free air cooling. To lower the cost of the infrastructure, a hybrid redundancy model was chosen where only 10 per cent of the facility supporting the data storage and disaster recovery systems will have electrical and cooling redundancy through UPS and generator.

Although the study is not yet completed, researchers have estimated a cost of approximately $30 million to build the first 8-megawatt phase of the data centre. The cost includes the building core, mechanical, electrical, cooling and a dual feed connection to the electrical grid.

Summary of green community cloud benefits

- Leverage the existing CANARIE.
    - *CANARIE operates a large, advanced optical network that can be used to advantageously locate data centres or community clouds in prime locations (such as those with access to infrastructure that can utilize waste heat and a low-emission electricity grid). Due to the high-speed nature of CANARIE, one or a number of community clouds could be located along the existing network at a significant cost advantage compared to expanding the network to remote locations.*

- The community cloud could be located in areas where the ability exists to use recovered heat generated by a data centre and where low-emission grid-connected electricity is readily available.
    - *By locating community clouds in provinces with an existing low-emission electricity supply, emissions from the operation of the data centre will be decreased and may be eligible to generate carbon credits. Furthermore, in remote locations, it may be technically and/or economically infeasible to utilize waste heat from a community cloud data centre (although waste heat could conceivably be used for space heating applications, were that necessary in a remote facility). In an urban centre, it is more likely that district heating systems or other immediate uses for waste heat will be available, allowing for its efficient use.*
- Provide an ICT research platform to develop systems and applications targeted at community clouds.
    - *Community clouds are a relatively new concept and, as such, in-depth research pertaining to the software, hardware and infrastructure surrounding community clouds (specifically to address the needs and concerns of educational institutions) may be warranted. Were CANARIE to develop a community cloud computing strategy for its network, its existence could be leveraged to perform further research to improve and refine the concept. CANARIE is particularly well placed to play a role in this research, since many of its stakeholders are members of the research community, and due to CANARIE's ongoing role as an administrator of research grants and funding. Furthermore, the community cloud could not only provide computing resources, it could host a centralized document and data repository for research scientists and academics across the country that could be easily and rapidly accessible from member organizations. Valuable information is constantly being generated by CANARIE's stakeholders. Acting as a library for this vast array of knowledge (perhaps in concert with the National Archives), CANARIE can reinforce its science and research strengths. This type of application would leverage CANARIE's very high-speed network, allowing researchers to quickly and easily access large data sets.*
- Cloud resources can be added incrementally as use and processing requirements increase, likely reducing the overall cost of capital to individual institutions.
    - *Universities must spend significant amounts of capital to obtain and maintain the currency of their data centres. With the economies of scale that a CANARIE community cloud could achieve, and due to the rapid depreciation of capital assets in the ICT sector, these capital expenditures could likely be reduced if Universities participated in a community cloud. Also, with virtualization technology, most of the specific requirements of existing systems can be accommodated on standard computing platforms, taking further advantage of economies of scale.*
- Cloud computing and virtualization make more effective use of resources and energy.
    - *According to the Uptime Institute, typical facilities running general purpose servers run, on average, 5 to 15 per cent of their maximum computing capacity, yet these systems consume nearly as much power as they do when fully active. Under-utilization of systems is often the cause for oversized*

infrastructure (cooling, generators, UPS, mechanical, electrical), which account for a large amount of data centre inefficiency. By consolidating systems and more efficient server provisioning, cloud computing and virtualization can increase system utilization into the 40–60 per cent range, thus improving the power efficiency of the IT equipment and infrastructure.[45]

- Because of their "on-demand" nature, community clouds can provide greater flexibility to scientists requiring high performance computing (HPC).
    - *Research conducted at Universities often requires HPC; however, due to the diverse nature of the research conducted, the capacity of the HPC infrastructure may not always operate at its full potential. With many institutions and more users accessing a centralized HPC system hosted at a community cloud, the overall utilization of the resources could be increased. Furthermore, the community cloud infrastructure would provide access to an HPC facility for institutions that cannot afford to develop their own.*
- The management and monitoring of the cloud can be managed by CANARIE and designed specifically to address the concerns of educational and research institutions.
    - *There are clear trends toward cloud computing and the concept of green ICT—influential stakeholders in the ICT and computing industry are making significant investments and progress in clouds and green ICT. The establishment of a community cloud data centre operated and administered by CANARIE on behalf of its members is an opportunity for CANARIE to leverage its physical and figurative network and provide a desirable service to its members.*

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[45] J. Koomey, K. G. Brill, W. P. Turner, J. R. Stanley and B. Taylor, September 2007, "A simple model for determining true total cost of ownership for data centers," Santa Fe, NM: The Uptime Institute, available at www.uptimeinstitute.org; VMware white paper, "How VMware virtualization right-sizes IT infrastructure to reduce power consumption."

Policy implications for key stakeholders

As described in the Discussion section above, the three scenarios investigated in this study do not generally make a compelling case for relocating or modifying existing University data centres from a financial point of view. However, as envisioned in the alternative approach, a community cloud, accessed via CANARIE's high-speed optical network, could have numerous financial, environmental and administrative benefits for Universities, while leveraging CANARIE's existing infrastructure and expertise.

This section of the report provides a summary of policy implications and concrete recommendations for Universities, data centres, the federal Canadian government, provincial governments and, finally, CANARIE itself.

Universities

One factor unique to Universities that became apparent during discussions with University ICT personnel is that ICT equipment is often highly distributed and fragmented into numerous small "data closets," which might house one or two racks. This is very likely a result of the way in which Universities are organized, where numerous semi-autonomous departments exist within the larger University infrastructure. Faculty and staff within these departments frequently operate HPC equipment independently of the main data centres, as they often receive funds for such equipment via research grants. Many faculty and staff may also wish to have their computing equipment close by and immediately accessible.

This fragmentation is changing—some University ICT departments are working to integrate data closets across the University into the main data centres, offering faculty the option of locating their independent research ICT equipment within the main data centres. The benefits of consolidating ICT equipment, especially expensive and specialized HPC equipment, could be realized on an inter-University level as well, however.

Because HPC is a resource that is mostly used on a project basis, HPC resources may have periods of high use followed by periods of low usage—in other words, HPC resources may not always be operated to the extent that they can be. Consolidating HPC resources in a community cloud accessible to Universities via CANARIE would be expected to reduce capital expenditures, increase access and improve the quality of HPC equipment for Universities.[46]

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[46] For instance, please see, "Cloud computing and public policy: Briefing paper for the ICCP Technology Foresight Forum," Organisation for Economic Co-operation and Development (OECD), Directorate for Science, Technology and Industry, 14 October 2009, available at www.oecd.org/dataoecd/39/47/43933771.pdf.

Conceptually, each participating University could allocate a small portion of their ICT budgets to operate the HPC community cloud. Furthermore, when applying to granting agencies for research funding, faculty could request funds to access and improve the shared HPC community cloud resource as opposed to funds to purchase, install and operate their own independent HPC equipment. In this way, the benefit of improved HPC resources is strengthened and shared by the entire University community.

Second, as leading research and teaching institutions, Universities have begun using their own backyards as living laboratories—demonstrating, testing and teaching new approaches and concepts using the University campus itself, bringing students and researchers outside of the classroom. For instance, the Integrated Learning Centre at Queen's University in Kingston was designed such that its "mechanical, electrical and structural systems are monitored in real-time and left open to view, to show how sustainable practices can be incorporated into building design."[47] In another example, the University of Toronto has conducted extensive social marketing research through its Rewire program, using staff, students and faculty to improve and refine the program, while reducing energy consumption at the University.[48]

A community cloud HPC facility located at a University could be used as a living laboratory in the same way. For instance, a non-system critical segment of such a facility could be used to give computer science students hands-on experience in managing a data centre. The facility could also be used to research and develop new cloud computing services in the area of storage, privacy, security and HPC that would be better adapted to university and institutional needs.

Living laboratories are beneficial to Universities because they simultaneously enhance the teaching and research experiences and can provide a platform to boost collaborations with leading Canadian cloud services providers.

Third, as commonly stated, measurement is a critical step in allowing appropriate management of resources, which applies equally to University data centres as it does elsewhere. This study found that electricity monitoring activities at University data centres did not include data centre specific data logging; however, some instantaneous measurements and nameplate equipment ratings were available.

Unfortunately, this level of measurement is unlikely of sufficient quality to allow conformance with the variety of monitoring activities required to generate high-quality offsets. Ideally, data centre electricity consumption would be monitored at as disaggregated a level as possible with, at a

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[47] See http://livebuilding.queensu.ca.

[48] See http://sustainability.utoronto.ca/projects/rewire.htm.

minimum, daily historic logging of electricity consumed by the entire data centre (including auxiliary), the electricity CRAC units (or in cases of central chilling infrastructure, cooling delivered) and the electricity input and output of the UPS.

In addition to supporting the generation of higher quality offsets, more significant monitoring activities would allow ICT personnel to more easily measure and improve the performance of their equipment.

Finally, some Universities have already begun to transfer some of their computing needs to third-party vendors. For instance, the University of Alberta has outsourced their alumni email service to a third party with data centres located in Ontario.

Although off-loading data centre activities to a third party will reduce the carbon footprint of the University, this action may not guarantee an overall reduction in emissions from data centre activities. If the electricity supply to the third party data centre were to be supplied by a source with a greater GHG intensity, then overall emissions would increase, while decreasing the emissions from the University. It is therefore important that when outsourcing these services, Universities consider the characteristics of the data centre to which these activities are being transferred.

The establishment of an HPC community cloud by Universities in partnership with CANARIE could have numerous financial, environmental, administrative and pedagogical benefits to Universities. This report recommends that Universities collaborate with CANARIE, funding institutions, and governments along with staff, students and faculty to establish one or more green HPC data centres, accessible via CANARIE.

Data centres

When mainframe computers began to be widely used in commercial settings 40 to 50 years ago and networked connections began to be made between databases in different jurisdictions, policy-makers realized that there were important public policy issues in relation to personal identity and privacy, information and network security, access to information, and intellectual property rights that were raised by the electronic processing, communication and storage of information. Over the past 20 to 30 years, the development of personal computers and the Internet; the rapid growth of e-finance, e-commerce, e-government, e-health and e-education; the globalization of many economic and social activities through the Internet; and concerns about cyber-crime, cyber-security and the potential for cyber-warfare have raised similar issues in a much wider and more complex context. Today, the rise of cloud computing—along with other changes taking place in the architecture of information and communications technology infrastructure—is raising these issues anew.

In *Cloud Computing and Public Policy*, a briefing paper prepared for an OECD Technology Foresight Forum that took place on 14 October 2009, Michael R. Nelson, Visiting Professor of Internet Studies at Georgetown University, identified the following set of public policy issues raised by cloud computing:

- portability, competition and innovation;
- research;
- access to the cloud;
- e-government and open standards; and
- security, privacy and accountability, including intellectual property and liability and consumer protection.[49]

Each of these issue areas is complex and there are important connections between them so that, for example, policy decisions taken with respect to security and privacy may affect the scope of competition and innovation. As Nelson noted, "many of the public policy issues…raised by cloud computing are similar to Internet policy issues we have been struggling with for at least fifteen years." As he went on to point out, however, addressing these issues for cloud computing will be at least as difficult, for the following reasons:

- Because the cloud is inherently global, policy solutions must be cross-jurisdictional;
- Because the cloud is a many-to-many medium, it is not always easy to determine who is responsible for what; and
- Because cloud technology and cloud applications are evolving quickly, government policy must be flexible and adaptable.

To enable Canadian consumers, businesses, governments and public institutions to take advantage of the benefits promised by cloud computing—and to support the development of Canadian-based cloud computing service providers—the federal government will need to systematically assess the public policy issues raised by cloud computing for users and service providers; review existing policies, laws and regulations to identify areas that need to be updated as well as gaps that need to be filled; and take action in consultation and coordination with affected stakeholders, including other levels of government.

The federal government is currently well positioned to update policies in a number of main areas in which cloud computing is having an impact. In the past year, major reviews have been completed of the Personal Information Protection and Electronic Documents Act (PIPEDA) and of copyright

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[49] "Cloud computing and Public Policy," 2009, Organisation for Economic Co-operation and Development, available at www.oecd.org/dataoecd/39/47/43933771.pdf.

policy; the resulting legislation has been tabled in Parliament. In addition, in its March 2010 Speech from the Throne, the federal government announced its intention to develop a cyber-security strategy for Canada, as well as a digital economy strategy. It appears that the latter initiative may offer an opportunity for conducting a comprehensive review across different policy areas that will be needed to systematically address the issues raised by cloud computing. *Improving Canada's Digital Advantage: Strategies for Sustainable Prosperity*, the digital economy consultation document that was released in May 2010, sought input on a number of questions raised by cloud computing, including its potential impact on ICT adoption by small- and medium-sized enterprises (SMEs); its potential to improve the efficiency and effectiveness of government operations; privacy and security concerns; and business opportunities for Canada's ICT sector. A number of submissions to the consultation process have supported development of cloud computing policies and strategies.[50]

Federal government

In addition to the public policy issues discussed in the previous section, the results of the study have other important policy implications for the federal government—particularly the option of establishing one or more community cloud computing centres to serve the needs of Canadian Universities.

As mentioned in the previous section, on 10 May 2010 the Ministers of Industry, Heritage and Human Resources and Skills Development published a consultation paper, *Improving Canada's Digital Advantage: Strategies for Sustainable Prosperity*, and launched a process to obtain input that would assist the federal government in developing a digital economy strategy for Canada as part of its overall economic agenda. The consultation paper identified five strategic themes and posed specific questions about what needed to be done to improve Canada's performance in each of these areas, which included capacity to innovate using digital technologies; building a world class digital infrastructure; growing the ICT industry; creating Canada's digital content advantage; and building digital skills for tomorrow. The paper acknowledged that Canada's Universities play a critical role in all of these areas by conducting research and building skills that support innovation in the development of digital infrastructure, the growth of Canada's ICT sector, and the creation of digital applications and content throughout our economy and society. The digital skills and innovations fostered by Canada's Universities, in turn, support innovation and skills development in every area of scientific discovery and technological advancement, in every sector of the economy, in the public sector, and throughout Canadian society.

The federal government spends a large amount of money each year to support the role played by Canadian Universities in Canada's innovation system, through fiscal transfers to the provinces, the

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[50] See http://de-en.gc.ca/2010/07/07/proposal-for-a-canadian-innovation-testbed/ for access to the Digital Economy Strategy consultation paper and submissions.

research funding provided through the granting councils, and other forms of support provided by organizations such as the Canada Foundation for Innovation (CFI) and CANARIE. In order to maximize the return to Canadians on this investment, it is critical that the digital infrastructure supporting the role played by Canadian Universities in Canada's innovation system operates efficiently and cost-effectively; that it be as open as possible to providing opportunities for collaborative research, technology commercialization, and citizen engagement; that it have the capacities needed to handle the HPC and networking requirements of University researchers; and that it serve as a driver of digital innovation, as well as an enabler of innovation in other areas.

The case studies presented in this report suggest that managers of Canadian University data centres are aware of these issues and are taking steps within the limits of their mandates and resources to address these requirements. It seems clear, however, that without policy leadership by the federal government and action through its various program and funding instruments, the results of the efforts being made at the Universities studied and elsewhere to upgrade the capacities of their data centres are likely to be fragmented, with different solutions being adopted by individual Universities in light of their local needs, and suboptimal in terms of their impact on the overall needs of Canada's innovation system. The results of the study also suggest that a preferred policy option for maximizing returns on the federal government's investments in University-based innovation and skills development would be to support the establishment of one or more community cloud computing centres powered by sources of renewable energy that would be accessible to University researchers through CANARIE. Among their other purposes, these green data centres might also serve as repositories of publicly funded research, accessible to the public, organizations and institutions through the Internet. They might also provide community cloud services to universities and research organizations in other countries.

Realizing this vision would require the federal government to address a number of policy issues, some of which would be specific to the creation of community cloud University data centres, others of which would be related to the public policy issues discussed in the previous section. The former set might include issues related to the mandate of CANARIE and the CFI; the terms and conditions governing fiscal transfers and the operations of the federal granting councils; the harmonization of policies regarding the transfer and storage of data generated by university researchers across jurisdictional boundaries, including policies regarding research ethics and confidentiality of research information; and the terms and conditions governing access to and use of publicly funded research. The latter set might include issues related to carbon pricing and markets for carbon credits, as well as general issues related to the protection of personal privacy, intellectual property rights, and information and network security.

To address these issues successfully, the federal government will need to engage with universities, the provinces, other stakeholders involved in the development of community cloud facilities, and possibly other governments. Because of the range of issues and stakeholders involved, it might be most effective to build this engagement around a specific project to establish one or more community cloud data centres for Canadian universities, led by CANARIE, as a test bed for technology and policy development.

In addition to the direct implications of the project for the federal government, in terms of its relationships with universities, the project has important indirect implications. According to the Treasury Board Secretariat's June 2008 *Government of Canada Profile of Information Technology (IT) Services,* the federal government spends around $5 billion per year on information technology, about 2 per cent of total government expenditures.[51] In a presentation on "Cloud Computing and the Canadian Environment" to the Global Government Cloud Computing Roundtable, which took place in Ottawa on 6 October 2009, Jirka Danek, CTO at Public Works Government Services Canada, called attention to Canada's advantages in the provision of cloud computing services—including its cooler temperatures, low-density population, IT expertise, quality construction standards, low-cost green energy, and legislative frameworks for protecting privacy—as well as to the advantages that could accrue to Canada generally, and the federal government in particular, from leadership in cloud computing. In addition to improving the efficient of its approximately 120,000 servers, these advantages could include leveraging cloud-related benefits, from the $12 billion allocated in the 2009 economic stimulus plan to IT and infrastructure projects, including $750 million allocated to developing leading edge research infrastructure through the CFI and $500 million to Canada Health Infoway to encourage the greater use of electronic health records.[52]

Although examination of the potential benefits of relocation of federal government data centres to sources of renewable energy was not part of the project mandate, we agree with Mr. Danek that "[t]here exists an opportunity for the Government of Canada to show leadership through the development of a broader Cloud Computing vision" and that a coordinated effort should be undertaken with the private sector, as well as with provincial, territorial and municipal governments. We note that a similar recommendation was made in *The Digital Economy and the Green Economy: Opportunities for strategic synergies*, the International Institute for Sustainable Development's submission to the federal government's Digital Economy Consultation.[53]

Provincial government

Education is a provincial and territorial responsibility. This study, therefore, also has relevance for possible policy responses by provincial and territorial ministries, with particular reference to the United Nations Decade of Education for Sustainable Development.

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[51] See www.tbs-sct.gc.ca/cio-dpi/webapps/technology/profil/profil-eng.pdf.

[52] A copy of Mr. Danek's presentation is available at http://www.cloudbook.net/canadacloud-gov.

[53] See www.iisd.org/pdf/2010/com_digital_economy.pdf.

In December 2002, the United Nations General Assembly adopted resolution 57/254 and designated UNESCO to lead the United Nations Decade of Education for Sustainable Development (DESD), spanning from 2005 to 2014. Focused on reorienting education on the long-term future of the economy, ecosystems and equity among peoples, the basic vision of the DESD is of a world in which everyone has the opportunity to benefit from education and learn the values, behaviours and lifestyles required for a sustainable future.

Education for sustainable development (ESD) offers learners at all levels a context for participation in more sustainable ways of living and, ultimately, fosters a sense of personal responsibility for the planet. ESD therefore requires a "whole school" approach, one that extends beyond teaching and research and addresses the entire planning and management of the educational facility. Walking the talk—demonstrating how an academic institution can demonstrate environmental responsiveness and innovation to its student body—is a key factor in reinforcing what is taught in the lecture halls and laboratories.

In formal education across Canada, there are now good examples of Ministries of Education creating frameworks for the integration of ESD into formal education in response to the UN-DESD, guided by a Pan Canadian Framework for ESD set by the Council of Ministers of Education Canada (CMEC). However, this focuses largely on primary and secondary education, where whole school approaches are being encouraged by the responsible provincial ministries. The same trend is not apparent in either technical and vocational education or advanced education. While most individual institutions of higher education have internal sustainable development committees working on a wide range of challenges related to energy efficiencies, fleet management, hazardous and other waste controls and so forth, including the greening of individual data centres, policies and practice vary widely across the country. As noted in the previous section, particular responses by data centres are fragmented and driven by local needs and policies of their institutions.

An opportunity exists through CMEC to identify opportunities for ministries responsible for advanced education to respond in a more collective fashion to the UN-DESD. Given the complexities of governance of higher institutions and their funding mechanisms and relationships with their provincial ministries, it is unlikely that a framework for response to the UN-DESD could easily be achieved. But green cloud computing centres could provide an entry point for cooperation. Establishing one or more centres could be considered a unique contribution to the UN-DESD, one that would demonstrate Canadian leadership internationally on how institutions of advanced education "walk the walk" of education for a sustainable future.

CANARIE

In addition to investigating the costs and benefits associated with the relocation or retrofitting of existing University data centres, this study provides a qualitative analysis of the benefits associated with a green HPC cloud for Universities via CANARIE.

Because CANARIE is well established, with numerous stakeholders and staff having requisite knowledge of the ICT industry, CANARIE is well placed to take a leadership role in the development and/or operation of a University community cloud data centre.

Of course, prior to embarking upon the establishment of an HPC community cloud, a more detailed cost-benefit analysis should be conducted. This would include an analysis of environmental benefits/impacts, capital and operating costs, revenues (from carbon credits or fees), the ICT requirement and the benefits/impacts on ICT services to Universities, and societal benefits/impacts. Ideally, such a study would also investigate the best path forward and role for CANARIE, via the analysis of several plausible organizational/financial structures, such as University owned/CANARIE administered, CANARIE owned/administered, and a public–private ownership/administrative structure.

By driving the adoption of leading-edge practices in Canada, we believe that CANARIE can leverage its existing position and clients to achieve tangible environmental, economic and societal benefits for its stakeholders, including Universities. This study recommends that CANARIE undertake a focused analysis of a community cloud and how it could work. If this analysis determines that a CANARIE community cloud is a feasible and desirable option, we recommend that CANARIE work with Universities, governments and other relevant stakeholders to establish community cloud data centre systems, leveraging the existing CANARIE high-speed optical network and stakeholders.

Glossary and acronyms

Bandwidth: Rate of data transfer, commonly measured in bits per second.

CANARIE: Canada's Advanced Research and Innovation Network. CANARIE manages an ultra high-speed network, which facilitates leading-edge research and big science across Canada and around the world. More than 40,000 researchers at 125 Canadian universities, 132 colleges and 49 CEGEPS (colleges of general and vocational education) use CANARIE, as well as scientists at many research institutes, hospitals, and government laboratories throughout the country. Their computer network is called CA*Net or CAnet.

Carbon credit (credit): A unit of greenhouse gas emission reductions, measured in tonnes of carbon dioxide equivalent and often verified by a third-party auditor, which can be traded within a voluntary or compliance market. Synonym: offset.

Carbon dioxide equivalent (CO_2e): Different greenhouse gases have different impacts upon the environment, quantified through their global warming potential. Carbon dioxide has a global warming potential of 1 and is the base unit for measurement and communication of greenhouse gas emissions. Other greenhouse gases contribute more significantly to the greenhouse effect on a per-unit mass basis; for instance, methane has a global warming potential of 21. Therefore, carbon dioxide equivalent is used as a measure of the total greenhouse gas impact, for communication and comparison.

Cloud computing: System of computing in which the computing resources being accessed are typically owned and operated by third-party providers on a consolidated basis in data centre locations.

CRAC (computer room air conditioner): A device that monitors and maintains the temperature, air distribution and humidity in a data centre.

Data centre: A data centre (sometimes spelled datacenter) is a centralized facility housing computer, telecommunications and storage systems. Data centres generally have specialized redundant mechanical and electrical systems to power and cool the ICT equipment.

FIT: The Feed-in-Tariff program provides guaranteed pricing for renewable electricity production (including hydroelectric), offering stable prices and long-term contracts.

FTE: A unit that represents one full-time employee, which is equal to approximately 2,080 hours worked in a year.

GHG: Greenhouse gas—these typically include the Kyoto gases: carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, hydrofluorocarbons and perfluorocarbons.

GigaPoP: Gigabit Point of Presence, an interface or access point to the high-speed CA*Net computer network.

Green community cloud (community cloud; cloud computing; cloud): A community cloud computing infrastructure designed for energy efficiency and using 100 per cent renewable energy for power.

ICT: Information and Communication Technology is a general term that describes any technology that helps to produce, manipulate, store, communicate and/or disseminate information.

kW: The kilowatt is equal to one thousand watts. A watt is a unit of power in the International System of Units (SI) that measures the rate of energy conversion. One watt is the rate at which work is done when one ampere (A) of current flows through an electrical potential difference of one volt (V). A small electric heater with one heating element can use one kW.

kWh: A kilowatt-hour is the amount of energy equivalent to a steady power of one kilowatt running for one hour. The average annual electrical energy consumption of a household in Canada is about 11,918 kilowatt-hours.[54]

NAS: Network Attached Storage. A centralized hard disk storage that is set up with its own network address, rather than being attached to the department computer, that is serving applications to a network's workstation users.

Offset: A unit of greenhouse gas emission reductions, measured in tonnes of carbon dioxide equivalent and often verified by a third-party auditor, which can be traded within a voluntary or compliance market. Synonym: Carbon credit (credit).

PDU: Power distribution units transform, provide circuit protection, and condition and distribute power across the data centre and within individual racks. Many PDUs provide metering of current flow and may have data logging and remote monitoring capabilities. S

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[54] Natural Resources Canada, 2007, *Comprehensive Energy Use Database*, "Residential sector, Canada," Table 1: Secondary energy use and GHG emissions by energy source, accessed June 2010.

PUE: The efficiency of a computer room is calculated as Total Power / ICT Equipment Power. This measure is called the Power Usage Effectiveness (PUE). Typically, existing computer rooms have a PUE ranging from 2.0 to 2.5, which indicates that the total power used by the data centre is often more than twice the power used by the ICT equipment.

Racks (sometimes called cabinets): Specialized shelving that house, power and sometimes provide cooling to ICT equipment in data centres. Typically, data centres will use racks that are designed to house 42 standard height (1.75 inches) devices or units, designated as 42U cabinets.

SAN: Storage Area Networks are data storage devices forming a dedicated system for centrally managing, storing and archiving data, composed of storage modules having controllers, disk drives, networking, and management software.

Server: A device consisting of hardware and software that may be running a server operating system, dedicated to providing ICT services such as printing, file storage, database storage, email applications, Web site hosting, etc.

Unit: Also called a “U,” this is a descriptor for one piece of ICT equipment (such as a server) located in a rack with other pieces of equipment (such as networking equipment). Each standard rack can fit 42 individual units; hence the common phrase “42U.”

UPS: Uninterruptible power supplies provide power conditioning and emergency power supply to data centre equipment.

Utility computing: Also known as on-demand computing, utility computing is the packaging of ICT resources—such as computation and storage—as a metered service, similar to a public utility offering such as electricity and water.

VA: Volt-ampere describes the amount of apparent power in an electrical circuit, equal to the product of voltage and current. The apparent power may differ from the real power for alternating current (AC) circuits, where voltage and current may be out of phase. The real power is equal to the apparent power multiplied by the power factor.

Virtualization: Technology that allows a physical server to host many virtual servers (or operating environments) mimicking a specific hardware and software platform, reducing the cost of hardware and the total power consumption. This technology also enables ICT managers to move legacy applications onto newer hardware platforms.

Appendix A: Summary notes and diagrams describing University data centres

University of Ottawa

There are two main data centres on the University of Ottawa ("Ottawa U") campus—one for administrative operations ("Vanier") and one for research operations ("Marion"). In approximately a year and a half, the Vanier data centre is to be relocated to a new building, where the waste heat will be used to heat 80 per cent of the building via a novel heat exchange system. Ottawa U has a central plant, which houses electrically driven central chillers, a natural gas reciprocating engine, a steam turbine and boilers. The reciprocating engine has been out of service since 2008, and the steam turbine operates based on a peaking power supply agreement with the Ontario Power Authority and rarely operates. A diesel generator located on the roof of the building provides an emergency backup power supply. Basic electrical and metering diagrams of the power distributions in Vanier and Marion are found in Figures A1 and A2.

The current Vanier data centre is 4,000 square feet; the new data centre will be 3,000 square feet. The move of the Vanier data centre will begin in mid-2011, with a plan to complete the move within six months. The new data centre will be designed as an IRC system, similar to the existing Marion data centre. The new data centre will reuse the extracted hot water to heat buildings.

The Vanier data centre is a raised floor design rated at approximately 130 kVA; it houses three UPSs and four CRACs, which supply the only cooling. Power consumption for the ICT equipment within the Marion data centre is rated at 80 kVA. The Marion data centre uses an IRC configuration to remove heat from the operation of the ICT equipment, using chilled water supplied by the Ottawa U central plant. It was estimated that central space cooling provides approximately 5 per cent of the total cooling load for the Marion data centre. Combined, Ottawa U representatives estimated that the Vanier and Marion data centres make up over 60 per cent of the total computing power on campus. The balance of the ICT equipment is in a number of other small centres, namely the Faculties of Medicine and Engineering.

During the site visit and kick-off meeting, a number of issues/barriers to the relocation of a University data centre were uncovered. First, it was determined that it was unlikely that Ottawa U would sell or transfer any carbon offset credits realized from a data centre relocation project, as they want to retain the right to the associated environmental attributes. Furthermore, the University has allocated financial resources to Physical Resource Services for energy efficiency projects, and therefore access to capital funds to perform environmental/efficiency improvements is less critical. For instance, the University has a budget of $750,000 to buy a solar photovoltaic power system.

Greater interest was expressed in the purchase of renewable electricity (e.g., Bullfrog Power) as opposed to the relocation of a data centre. Although the renewable electricity costs a premium, its purchase would not require any changes to systems and facilities, and waste heat from the data centre could be used beneficially on campus.

It was also expected that the University would experience difficulties transferring and storing data off site, especially for ICT equipment not owned by Computing and Communications Services but by faculty members who may wish to access their equipment.

Ultimately, the meeting participants felt that the relocation of the data centre to a remote facility powered by renewable energy was not practically feasible because:

- they believed that the GHG credits generated would be small compared to the cost of relocation;
- the University is currently recovering and reusing the heat generated by the ICT systems;
- they were concerned about the management, access and security of University data stored at remote sites; and
- they already have access to green energy if they wish to purchase it.

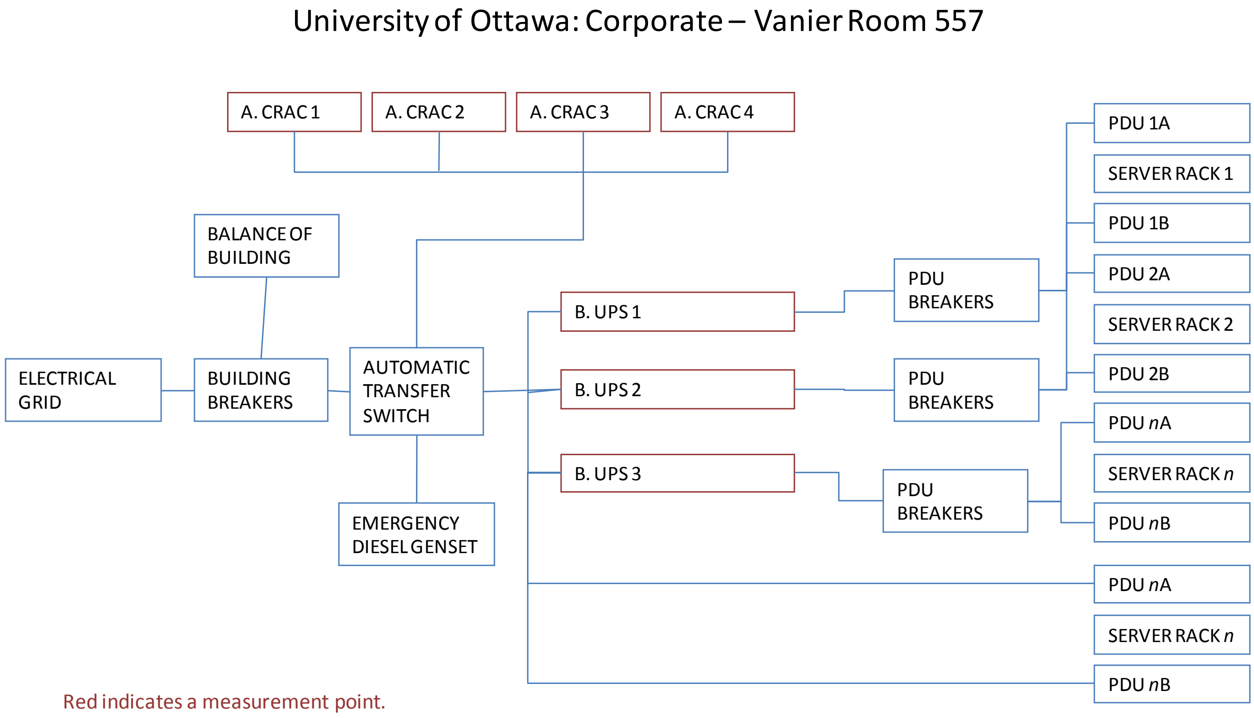


Figure A1.

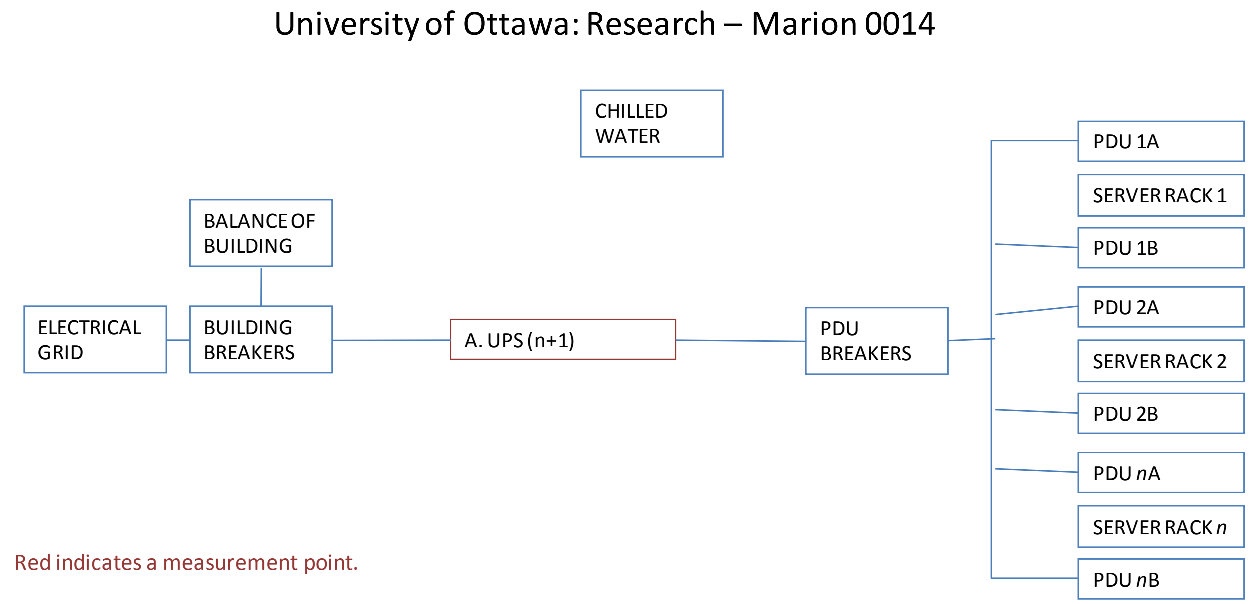


Figure A2.

Dalhousie University

Dalhousie University's main data centre is located in the basement of the Killam library. This data centre hosts the “GigaPoP” (the gateway to the high-speed CANARIE). Other, smaller networks to regional data centres (such as at research institutions, universities, and so forth) branch off from the GigaPoP. A second data centre ("Sexton") is located on the Sexton campus and is mainly used for data backup operations. The Sexton data centre is much smaller than the Killam data centre. Combined, the Killam and Sexton data centres represent over 90 per cent of the ICT equipment power use at Dalhousie, not including the Department of Computer Science. See Figures A3 and A4 for schematic diagrams documenting the power distributions of these data centres.

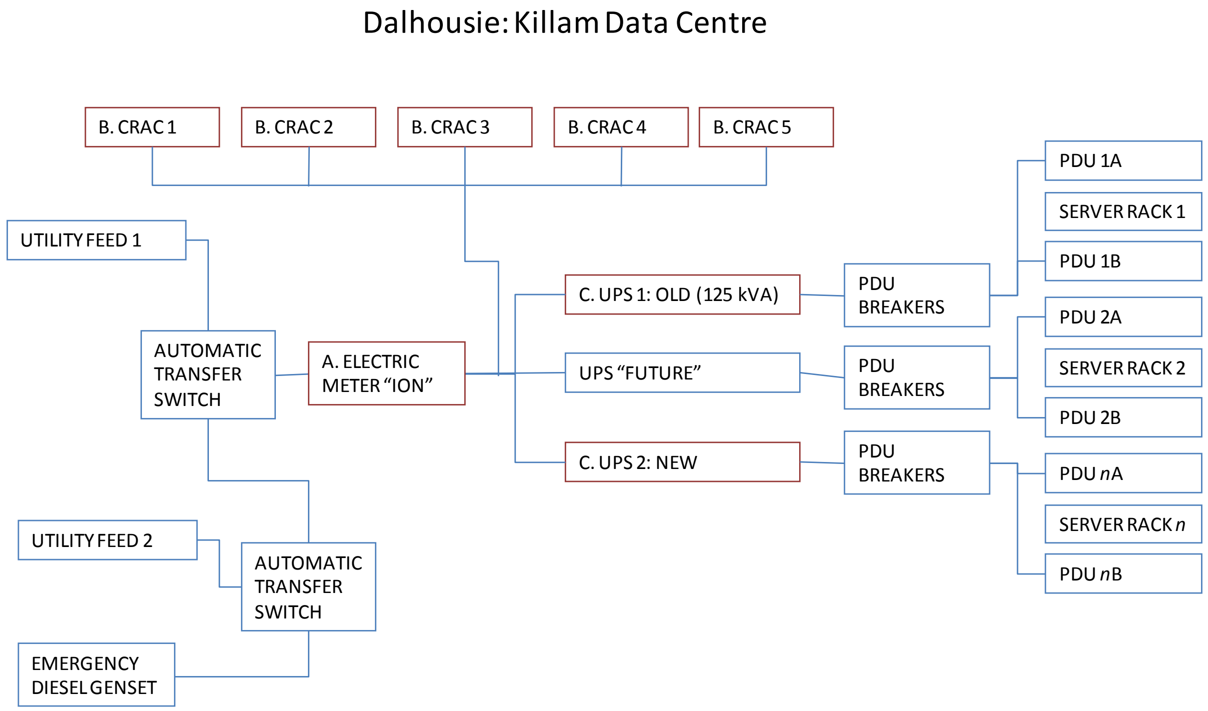
The Killam data centre is about 5,000 square feet, with a raised floor of about 12 to 18 inches. It contains three UPSs with a total average power input of 250 kW, which feed all of the ICT equipment in the data centre. Total electricity consumption for the Killam data centre (except for the lights) is measured via an ION metre. The Killam data centre can be fed by two separate electrical substations; the ION metre is located after the two sources from different substations (i.e., it will measure the electricity whether it is coming from one or both). The air conditioning is being supplied by five stand-alone CRACs. These air conditioning units are fed by electricity that does not go through the UPS, but this electricity is monitored using the ION metre. Air conditioning is accomplished with water and/or water glycol liquid. There were analog pressure gauges in evidence at the facility. There are four central PDUs in the Killam data centre. A 1,250 kVA emergency diesel generator is on site, with 650 kVA allocated to the data centre.

The Sexton data centre (1,000 square feet) is primarily used as a data backup facility, performing daily backups of the Killam data centre via a fibre optic ring and tape backup system. It has one UPS and one CRAC, which draw approximately 30 kVA and 35 kW, respectively. There is no backup power at the site.

Staff at Dalhousie indicated that they are beginning to virtualize some of the ICT equipment located at both data centres and also indicated that they see a potential to deploy all Sexton ICT equipment to a remote site.

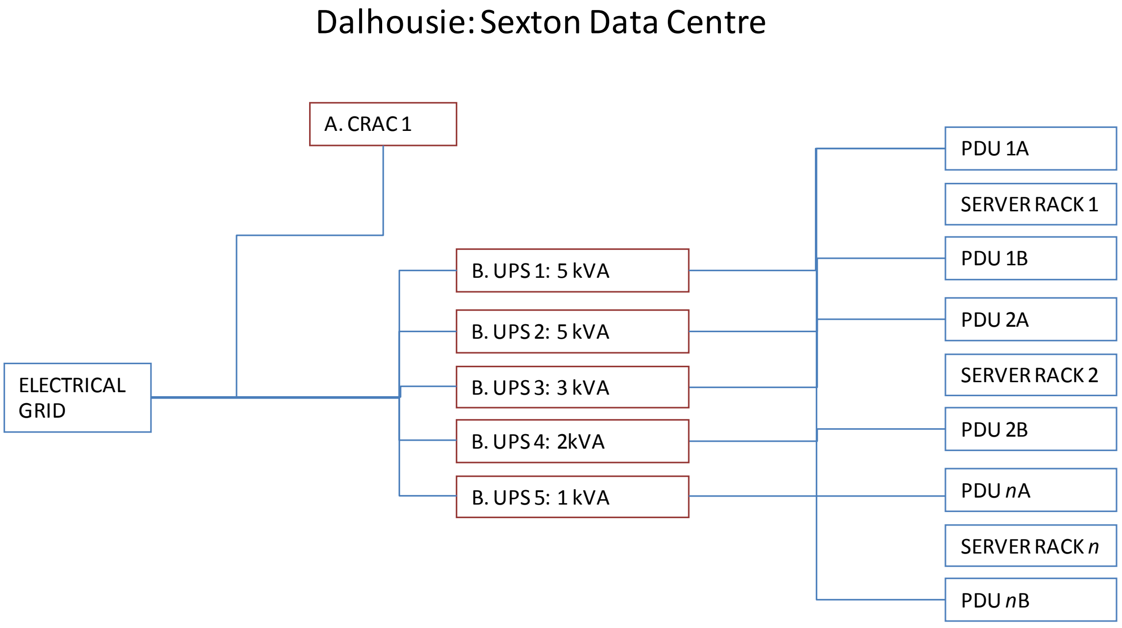
ICT personnel also stressed the importance of having redundant network connections, so if there was a problem with one loop connection, the other connection would provide the redundancy. This is reflected in the way that the existing data centre is set up, as there are currently two UPSs (one old, one new). The new one powers the entire facility, while the old one is a redundant supply for the "critical system components" (mainly telecom, telephone, networking, ERP system). Note that a third UPS will soon be added to provide electrical redundancy to all ICT systems in the data centre.

According to Dalhousie ICT staff, Nova Scotia is home to the highest concentration of universities per capita in the country. Dalhousie personnel described their idea to leverage this proximity and set up regional and redundant data centres for those universities and research institutions.


Dalhousie: Killam Data Centre

Red indicates a measurement point.

Figure A3.


Dalhousie: Sexton Data Centre

Red indicates a measurement point.

Figure A4.

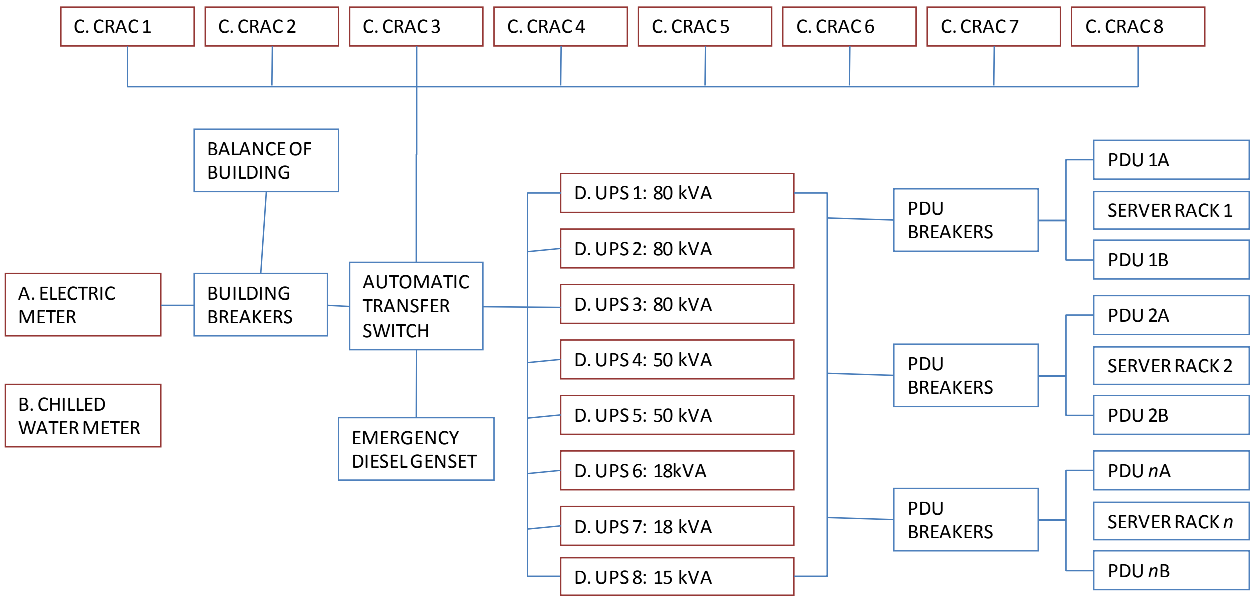
University of Alberta

There is one main data centre at the University of Alberta ("U of A") campus located in the General Services Building (see Figure A5 for a schematic diagram), with a smaller one located in downtown Edmonton, called Enterprise Square, in an office building managed by Bentall. Together, these data centres make up approximately one-third of the total computing power consumption, according to U of A staff. There are also numerous other machine rooms at U of A, with dozens (probably about 30) of ICT clusters/groups on campus. Staff indicated that recently, three of these clusters/groups merged (representing about 10 per cent of the processing power on campus) and they reduced the number of servers by about two-thirds. Administrative computing for certain applications (such as "PeopleSoft") has been outsourced to IBM in Markham, Ontario. The U of A has a central co-generation plant (boilers and a steam turbine), as well as a chilled water plant, which takes advantage of the North Saskatchewan River.

The General Services Building data centre is approximately 8,000 square feet and houses voiceover Internet protocol, research and HPC. The data centre is cooled by both individual CRAC units, as well as by a chilled water loop from the central plant at the University. While electricity is metered for the entire General Services Building (which houses a range of other services distinct from the data centre), the electricity consumed by the data centre itself is not measured. The General Services data centre uses nine UPS units with an average power output of 409 kW; nine CRAC units are also used in the data centre, with a total rated power input of 382 kW. Cooling is also provided via chilled water from the central plant; however, no direct metering of this cooling occurs.

Far less information is available concerning the Enterprise Square data centre. Based on conversations with U of A staff, one UPS with a rated capacity of 1,000 kW serves the site, with two CRAC units. This information could not be confirmed, however, and is therefore not included in the overall analysis.

U of A launched a green ICT program in the fall of 2009 and has recently hired an employee who will focus on green ICT. Staff also indicated that U of A has held very preliminary discussions with IBM and Hewlett Packard (HP) on the subject of a community cloud (as those firms could provide the required infrastructure); however, IBM and HP have not been able to find an attractive business case for such an effort. U of A staff would envision a regional network of community cloud data centres in British Columbia, Manitoba, Québec and the East Coast.



University of Alberta: General Services Building Data Centre (Room 175)

Red indicates a measurement point.

Figure A5.

Appendix B: Carbon footprint

University of Ottawa

Carbon footprint summary	
Average (kW)	
IT equipment	280
Cooling system	298
Auxiliary power	98
Total	676
Estimated (kWh/year)	
IT equipment	2,452,800
Cooling system	2,612,232
Auxiliary power	858,480
Total	5,923,512
Estimated emissions (tonnes CO_2e/year)	
IT equipment	417
Cooling system	444
Auxiliary power	146
Total	1,007

Dalhousie University

Carbon footprint summary	
Average (kW)	
IT equipment	280
Cooling system	346
Auxiliary power	98
Total	724
Estimated (kWh/year)	
IT equipment	2,452,800
Cooling system	3,030,960
Auxiliary power	858,480
Total	6,342,240
Estimated emissions (tonnes CO_2e/year)	
IT equipment	1,938
Cooling system	2,394
Auxiliary power	678
Total	5,010

University of Alberta

Carbon footprint summary	
Average (kW)	
IT equipment	409
Cooling system	382
Auxiliary power	143
Total	934
Estimated (kWh/year)	
IT equipment	3,585,468
Cooling system	3,345,444
Auxiliary power	1,254,914
Total	8,185,826
Estimated emissions (tonnes CO_2e/year)	
IT equipment	2,316
Cooling system	2,161
Auxiliary power	811
Total	5,288

Combined University footprint

Carbon footprint summary	
Average (kW)	
IT equipment	969
Cooling system	1,026
Auxiliary power	339
Total	2,335
Estimated (kWh/year)	
IT equipment	8,491,068
Cooling system	8,988,636
Auxiliary power	2,971,874
Total	20,451,578
Estimated emissions (tonnes CO_2e/year)	
IT equipment	4,671
Cooling system	5,000
Auxiliary power	1,635
Total	11,305

Appendix C: Data collection template

Data Centre Area					
Approximate data centre floor space	8,000	sq. ft.			
Total floor area per rack	80	sq. ft. per rack			
Total # of racks in data centre	100				
Energy and power use/costs	**Units**	**Servers**	**Disk storage**	**Tape storage**	**Networking**
Average (typical) price per U	$				
Average Power Rating per U	W	385	200	50	150
% of racks	%	80%	8%	2%	10%
# of racks	-	80	8	2	10
# of U's per rack	-	42	42	42	42
% filled	%	76%	76%	76%	76%
Total power use/rack	kW/rack	12.3	6.4	1.6	4.8
UPS Model (See "D." on diagram)	**Units**	**Rated Power Output (kW)**	**Average Power In (kW)**	**Average Power Out (kW)**	
	kW				
	kW				
	kW				
CRAC Model (See "C." on diagram)	**Units**	**Rated Cooling Capacity (btu/hr)**	**Rated Power In (kW)**	**Average Power In**	
	btu/hr; kW	-		-	
	btu/hr; kW				
Building Electric Meter (See "A." on diagram)	**Units**	**Annual Electricity Consumed (2009)**			
	kWh				
Building Chilled Water (See "B." on diagram)	**Units**	**Annual Electricity Consumed (2009)**			
	cubic meters				
Type of Refrigerant Replaced	**Units**	**Volume Replaced in 2009**			
	L				
Other capital costs	**Units**				
Rack set up costs (including cabling, routers and rack)	$/rack	3,000			
Inert gas fire suppress costs	$/sq. ft.				
Average price of electricity paid by University	$/kWh				
System Categorization	Number of Racks	Note			
High Performance Computing		Scientific and Engineering			
Email					
E-Learning					
Web portals		Intranet and Internet			
Enterprise applications		Financial, HR, ...			
Database					
Storage		SAN, NAS			
Other					
Other					
Staffing					
	Units	**IT**	**Facilities**	**Other**	**Security**
People per shift	-	3	1	0	1
Shifts per day	-	1	1	1	3

Appendix D: Co-location costs analysis

Example of the cost breakdown to co-locate the combined IT racks of the three Universities at a commercial data centre: two examples are provided; one is an equivalent Tier III co-location centre in British Columbia (BC) and the other is an equivalent Tier II co-location centre in Québec (QC). Both centres operate on hydroelectricity.

Co-location requirements (3 Universities)		
Number of racks	**265**	
Rack density (sq. ft.)	**35**	
Power per rack (W)	**3,658**	
Power per sq. ft. (W)	**209**	
Unit costs ($C)	**Scenarios**	
	BC – Tier III	**QC – Tier II**
Cost to set up rack	-	$ 800
Cost per IT kW per month	$273	-
Cost per rack per month	$325	$920
Setup cost ($C)	**Scenarios**	
	BC – Tier III	**QC – Tier II**
Cost to set up racks	-	$212,000
Racking up and cabling	$795,000	$795,000
Cost to set up cages	-	$66,250
Project management, configuration, testing	150,000	$150,000
Optical network to CANARIE	-	$1,000
Total setup	**$945,000**	**$1,224,250**
Yearly operating costs ($C)	**Scenarios**	
	BC – Tier III	**QC – Tier II**
Connection to CANARIE	$27,000	$6,900
Cost of rack space	$1,033,500	-
Operating cost	$3,175,427	$2,925,600
Total operating costs	**$4,235,927**	**$2,932,500**

Appendix E: Relocation cost analysis

Method

From the information collected, we have estimated the power and space usage of the University data centres and made the assumption that the remote facilities would require identical space and power. For each scenario, we have established the capital costs and the operating costs.

The cost to construct the hydroelectric generating station and the power transmission line make up the capital investment for the power generation at the remote site. The capital investment for the data centre are the combined cost of constructing the data centre (with electrical, UPS, cooling, mechanical, etc.), the cost of land and permits, racking up, cabling and equipment testing, project management, configuration and testing of applications, and the building of the optical network linking the remote site to CANARIE.

We have calculated an equivalent annualized cost for both the generating station and the data centre. To calculate the annualized investment cost, we used the ordinary annuity formula:

$$P = R\left[\frac{1-\frac{1}{(1+i)^n}}{i}\right] = R \cdot a_{\overline{n}|i}$$

In the formula, P = the capital expenditure (investment), R = annualized cost, n = number of periods, and i = is the interest rate per period.

We assumed a lifetime of 15 years for the data centre facilities and 25 years for the power generating station. Thus, for all three analyses, the calculation was made using one period per year, with an annual interest rate of 4.05 per cent, which is based on the average yield of Government of Canada 10-year marketable bonds (series V122487) during the period June 2007 to April 2010.

The "Net (incremental) operations cost" for each scenario only takes into account operating costs and excludes the equivalent annualized cost of the capital expenses.

Scenario 1

We have assumed that the remote data centre would be constructed in a community located approximately 100 kilometres from the University. The cost of deploying CANARIE between the University and the new site is added to the project capital expenditure.

Except for the cost of electricity and the cost to operate the link to CANARIE, we are assuming that the operating cost of the remote data centre will be the same as for the campus data centre. For this reason, this scenario only compares the cost of electricity at the University site to the operating and maintenance (O&M) cost of the generating station at the remote site. The equivalent annualized cost for the generating station and data centre is then added to the O&M cost to produce the "Total operations costs." In this scenario, the "Net (incremental) operating cost" is the O&M cost of the generating station, minus the operational costs for the baseline data centre—in this case, grid electricity at the University campus.

Scenario 2

We have assumed that the data centre would be constructed in an urban centre having access to low-emission grid electricity. For the study, we have assumed that the data centre would be located in Montréal. In this scenario, the cost of land in an urban setting is assumed to be more than three times the cost of land in a remote area, but the cost of connecting to CANARIE is assumed to be much less than the remote scenario (about $26,000) because of the urban setting. All other data construction costs are assumed to be the same.

Except for the cost of electricity and the cost to operate the link to CANARIE, we are assuming that the operating cost of the remote data centre will be the same as for the campus data centre. For this reason, this scenario only compares the cost of electricity at the University site to the cost of electricity at the urban site. The equivalent annualized cost for the data centre is then added to the cost of electricity to produce the "Total operations costs." In this scenario, the "Net (incremental) operating cost" is the cost of electricity at the urban site, minus the operational costs for the baseline data centre—in this case, grid electricity at the University campus.

Scenario 3

In this scenario, we are not relocating the data centre, but we are constructing a waste heat exchanger to improve the efficiency of the existing data centre. The capital cost in this scenario is the cost to construct the heat exchanger.

Except for the cost of maintaining the heat exchanger, we are assuming that the operating cost of the data centre will be the same as the status quo. The equivalent annualized cost for constructing the heat exchanger is then added to the cost of electricity to produce the "Total operations costs." In this scenario, the "Net (incremental) operating cost" is the cost of electricity plus the annualized construction cost and the operating cost of the heat exchanger, minus the operational costs for the baseline data centre—in this case, grid electricity at the University campus.

University of Ottawa

University of Ottawa data centre specifications		Notes (see Notes tab)
Tier level (II, III, or IV)	**II**	1
Number of racks	**71**	2
Rack density (sq. ft.)	**68**	3
Power per rack (W)	**3,944**	4
Power per sq. ft. (W)	**141**	5
Power for IT equipment (kW)	**280**	6
Power for cooling (kW)	**298**	7
Power for lighting and other auxiliary use (kW)	**98**	8
Total data centre power (kW)	**676**	9
Power Usage Effectiveness (PUE)	**2**	10
Total area (sq. ft.)	**4,800**	11
Active area (sq. ft.)	**4,800**	12
Empty area (sq. ft.)	**0**	13
Cost of electricity at University ($/kWh)	**$0.088**	14
Cost of electricity in Montreal, QC ($/kWh)	**$0.049**	15
Cost of land (remote)	**$10**	34
Cost of building (urban)	**$38**	72

Scenario 1: Capital costs		
Power generation capital cost		16
Power generation capacity (kW)	**2,000**	17
Transmission line length (m)	**500**	18
Cost to build small hydro generating plant ($M/MW)	**6.23**	19
Cost to build transmission line ($M/km)	**1.48**	20
Yearly water rights and land taxes (% of all yearly costs)	**10%**	21
Operations and maintenance ($/kW/year)	**39**	22
		23
Total cost to build electrical generating station ($)	**$12,469,277**	24
Total cost to build transmission lines ($)	**$739,000**	25
Total power generation investments	**$13,208,277**	26
		27
Remote data centre building & infrastructure capital cost		28
Data centre construction cost for each kW of IT (based on Tier)	**$13,772**	29
Data centre construction cost for each sq. ft. active space	**$331**	30
Data centre construction cost for each sq. ft. empty space	**$209**	31
Data centre construction cost for waste heat exchanger	**$150,000**	32
Data centre building cost—with electrical, UPS, cooling, mechanical, etc.	**$5,592,714**	33
Cost of land and permits	**$57,600**	34
Racking up, cabling, testing	**$213,000**	35
Project management. Configure and test applications	**$150,000**	36
Optical network to CANARIE	**$500,000**	37
Total data centre capital investments	**$6,513,314**	38
Capital cost—power generating station	**$13,208,277**	
Capital cost—IT assets	**$713,000**	
Capital cost—building, Class 1, non-residential	**$5,650,314**	
Labour & project management	**$150,000**	
Total capital cost	**$19,721,592**	39

Scenario 2: Capital costs		
Urban data centre building & infrastructure capital cost		
Data centre construction cost for each kW of IT (based on Tier)	**$13,772**	29
Data centre construction cost for each sq. ft. active space	**$331**	30
Data centre construction cost for each sq. ft. empty space	**$209**	31
Data centre construction cost for waste heat exchanger	**$150,000**	32
Data centre building cost—with electrical, UPS, cooling, mechanical, etc.	**$5,592,714**	33
Cost of land and permits	**$182,400**	72
Racking up, cabling, testing	**$213,000**	35
Project management: Configure and test applications	**$150,000**	36
Optical network to CANARIE	**$26,000**	37
Total data centre capital investments	**$6,164,114**	39
Capital cost—power generating station	-	75
Capital cost—IT assets	**$239,000**	76
Capital cost--building, Class 1, non-residential	**$5,775,114**	77
Labour & project management	**$150,000**	78
Total capital cost	**$6,164,114**	39

Scenario 3: Capital costs		
Heat exchanger capital cost		
Data centre construction cost for waste heat exchanger	**$150,000**	32
Data centre construction cost for waste heat exchanger	**$150,000**	
Project management for installation of heat exchanger system	**$50,000**	79
Total data centre investments	**$200,000**	
Total capital cost	**$200,000**	39
Capital cost—power generating station	-	75
Capital cost—IT assets	-	76
Capital cost—building, Class 1, non-residential	**$150,000**	77
Labour & project management	**$50,000**	78
Total capital cost	**$200,000**	39

Scenario 1: Operating costs	Scenarios		
Cost of operations (annual)	Status quo	Remote off-grid	42
Electrical	$520,590		43
Operation and maintenance of generating station		$78,597	44
Yearly power generating station water rights and land taxes		$94,440	45
Operation and maintenance of CANARIE link		$50,000	99
Equivalent annualized cost of data centre (15 years)		$587,865	46
Equivalent annualized cost of power generating station (25 years)		$849,962	47
Total operations costs	$520,590	$1,660,863	48
Net (incremental) operations cost	$(297,553)		74
Scenario 2: Operating costs			
Capital cost for relocating data centre to non-remote location	$6,164,114		39
Equivalent annualized cost of moving data centre (15 years)	$556,347		
Cost for electricity (assume location in Montreal, QC)	$290,971		80
Operation and maintenance of CANARIE link	$21,600		99
Total operations costs	$868,919		48
Net (incremental) operations cost	$(208,018)		74
Scenario 3: Operating costs			
Data centre construction cost for waste heat exchanger	$150,000		
Equivalent annualized cost of construction cost for waste heat exchanger (15 years)	$13,538		
Annual maintenance cost for heat exchanger	$5,000		
Annual cost of electricity for University	$520,590		
Total operations costs	$525,590		48
Net (incremental) operations cost	$5,000		74

Scenario 1 header row margin number: 41

Dalhousie University

Dalhousie University data centre specifications		**Notes (see Notes tab)**
Tier level (II, III, or IV)	**II**	1
Number of racks	**79**	2
Rack density (sq. ft.)	**64**	3
Power per rack (W)	**3,544**	4
Power per sq. ft. (W)	**144**	5
Power for IT equipment (kW)	**280**	6
Power for cooling (kW)	**346**	7
Power for lighting and other auxiliary use (kW)	**98**	8
Total data centre power (kW)	**724**	9
Power Usage Effectiveness (PUE)	**3**	10
Total area (sq. ft.)	**5,024**	11
Active area (sq. ft.)	**5,024**	12
Empty area (sq. ft.)	**0**	13
Cost of electricity at University ($/kWh)	**$0.079**	14
Cost of electricity in Montreal, QC ($/kWh)	**$0.049**	15
Cost of land (remote)	**$10**	34
Cost of building (urban)	**$38**	72

Scenario 1: Capital costs	
Power generation capital cost	
Power generation capacity (kW)	**2,000**
Transmission line length (m)	**500**
Cost to build small hydro generating plant ($M/MW)	**4.61**
Cost to build transmission line ($M/km)	**1.48**
Yearly water rights and land taxes (% of all yearly costs)	**10%**
Operations and maintenance ($/kW/year)	**58**
Total cost to build electrical generating station ($)	**$9,227,138**
Total cost to build transmission lines ($)	**$739,000**
Total power generation investments	**$9,966,138**
Remote data centre building & infrastructure capital cost	
Data centre construction cost for each kW of IT (based on Tier)	**$13,772**
Data centre construction cost for each sq. ft. active space	**$331**
Data centre construction cost for each sq. ft. empty space	**$209**
Data centre construction cost for waste heat exchanger	**$150,000**
Data centre building cost—with electrical, UPS, cooling, mechanical, etc.	**$5,666,753**
Cost of land and permits	**$60,288**
Racking up, cabling, testing	**$237,000**
Project management. Configure and test applications	**$150,000**
Optical network to CANARIE	**$500,000**
Total data centre capital investments	**$6,614,041**
Capital cost—power generating station	**$9,966,138**
Capital cost—IT assets	**$737,000**
Capital cost—building, Class 1, non-residential	**$5,727,041**
Labour & project management	**$150,000**
Total capital cost	**$16,580,179**

Scenario 2: Capital costs		
Urban data centre building & infrastructure capital cost		
Data centre construction cost for each kW of IT (based on Tier)	**$13,772**	29
Data centre construction cost for each sq. ft. active space	**$331**	30
Data centre construction cost for each sq. ft. empty space	**$209**	31
Data centre construction cost for waste heat exchanger	**$150,000**	32
Data centre building cost—with electrical, UPS, cooling, mechanical, etc.	**$5,666,753**	33
Cost of land and permits	**$190,912**	72
Racking up, cabling, testing	**$237,000**	35
Project management: Configure and test applications	**$150,000**	36
Optical network to CANARIE	**$26,000**	37
Total data centre capital investments	**$6,270,665**	39
Capital cost—power generating station	-	75
Capital cost—IT assets	**$263,000**	76
Capital cost--building, Class 1, non-residential	**$5,857,665**	77
Labour & project management	**$150,000**	78
Total capital cost	**$6,270,665**	39

Scenario 3: Capital costs		
Heat exchanger capital cost		
Data centre construction cost for waste heat exchanger	**$150,000**	32
Data centre construction cost for waste heat exchanger	**$150,000**	
Project management for installation of heat exchanger system	**$50,000**	79
Total data centre investments	**$200,000**	
Total capital cost	**$200,000**	39
Capital cost—power generating station	-	75
Capital cost—IT assets	-	76
Capital cost—building, Class 1, non-residential	**$150,000**	77
Labour & project management	**$50,000**	78
Total capital cost	**$200,000**	39

Scenario 1: Operating costs	**Scenarios**		41
Cost of operations (annual)	**Status quo**	**Remote off-grid**	42
Electrical	**$500,805**		43
Operation and maintenance of generating station		**$116,384**	44
Yearly power generating station water rights and land taxes		**$71,259**	45
Operation and maintenance of CANARIE link		**$50,000**	99
Equivalent annualized cost of data centre (15 years)		**$596,956**	46
Equivalent annualized cost of power generating station (25 years)		**$641,328**	47
Total operations costs	**$500,805**	**$1,475,926**	48
Net (incremental) operations cost	**$(263,163)**		74

Scenario 2: Operating costs		
Capital cost for relocating data centre to non-remote location	**$6,270,665**	39
Equivalent annualized cost of moving data centre (15 years)	**$565,964**	
Cost for electricity (assume location in Montreal, QC)	**$311,540**	80
Operation and maintenance of CANARIE link	**$21,600**	99
Total operations costs	**$899,104**	48
Net (incremental) operations cost	**$(167,665)**	74

Scenario 3: Operating costs		
Data centre construction cost for waste heat exchanger	**$150,000**	
Equivalent annualized cost of construction cost for waste heat exchanger (15 years)	**$13,538**	
Annual maintenance cost for heat exchanger	**$5,000**	
Annual cost of electricity for University	**$500,805**	
Total operations costs	**$505,805**	48
Net (incremental) operations cost	**$5,000**	74

University of Alberta

University of Alberta data centre specifications		**Notes (see Notes tab)**
Tier level (II, III, or IV)	**II**	1
Number of racks	**115**	2
Rack density (sq. ft.)	**70**	3
Power per rack (W)	**3,559**	4
Power per sq. ft. (W)	**117**	5
Power for IT equipment (kW)	**409**	6
Power for cooling (kW)	**382**	7
Power for lighting and other auxiliary use (kW)	**143**	8
Total data centre power (kW)	**934**	9
Power Usage Effectiveness (PUE)	**2.3**	10
Total area (sq. ft.)	**8,000**	11
Active area (sq. ft.)	**8,000**	12
Empty area (sq. ft.)	**0**	13
Cost of electricity at University ($/kWh)	**0.062**	14
Cost of electricity in Montreal, QC ($/kWh)	**0.049**	15
Cost of land (remote)	**$10**	34
Cost of building (urban)	**$38**	72

Scenario 1: Capital costs	
Power generation capital cost	
Power generation capacity (kW)	**2,000**
Transmission line length (m)	**500**
Cost to build small hydro generating plant ($M/MW)	**4.50**
Cost to build transmission line ($M/km)	**1.48**
Yearly water rights and land taxes (% of all yearly costs)	**10%**
Operations and maintenance ($/kW/year)	**72**
Total cost to build electrical generating station ($)	**$9,001,930**
Total cost to build transmission lines ($)	**$739,000**
Total power generation investments	**$9,740,930**
Remote data centre building & infrastructure capital cost	
Data centre construction cost for each kW of IT (based on Tier)	**$13,772**
Data centre construction cost for each sq. ft. active space	**$331**
Data centre construction cost for each sq. ft. empty space	**$209**
Data centre construction cost for waste heat exchanger	**$150,000**
Data centre building cost—with electrical, UPS, cooling, mechanical, etc.	**$8,431,134**
Cost of land and permits	**$96,000**
Racking up, cabling, testing	**$345,000**
Project management. Configure and test applications	**$150,000**
Optical network to CANARIE	**$500,000**
Total data centre capital investments	**$9,522,134**
Capital cost—power generating station	**$9,740,930**
Capital cost—IT assets	**$845,000**
Capital cost—building, Class 1, non-residential	**$8,527,134**
Labour & project management	**$150,000**
Total capital cost	**$19,263,064**

Scenario 2: Capital costs		
Urban data centre building & infrastructure capital cost		
Data centre construction cost for each kW of IT (based on Tier)	**$13,772**	29
Data centre construction cost for each sq. ft. active space	**$331**	30
Data centre construction cost for each sq. ft. empty space	**$209**	31
Data centre construction cost for waste heat exchanger	**$150,000**	32
Data centre building cost—with electrical, UPS, cooling, mechanical, etc.	**$8,431,134**	33
Cost of land and permits	**$304,000**	72
Racking up, cabling, testing	**$345,000**	35
Project management: Configure and test applications	**$150,000**	36
Optical network to CANARIE	**$26,000**	37
Total data centre capital investments	**$9,256,134**	39
Capital cost—power generating station	-	75
Capital cost—IT assets	**$371,000**	76
Capital cost--building, Class 1, non-residential	**$8,735,134**	77
Labour & project management	**$150,000**	78
Total capital cost	**$9,256,134**	39

Scenario 3: Capital costs		
Heat exchanger capital cost		
Data centre construction cost for waste heat exchanger	**$150,000**	32
Data centre construction cost for waste heat exchanger	**$150,000**	
Project management for installation of heat exchanger system	**$50,000**	79
Total data centre investments	**$200,000**	
Total capital cost	**$200,000**	39
Capital cost—power generating station	-	75
Capital cost—IT assets	-	76
Capital cost—building, Class 1, non-residential	**$150,000**	77
Labour & project management	**$50,000**	78
Total capital cost	**$200,000**	39

Scenario 1: Operating costs	Scenarios		
Cost of operations (annual)	**Status quo**	**Remote off-grid**	42
Electrical	**$508,711**		43
Operation and maintenance of generating station		**$143,154**	44
Yearly power generating station water rights and land taxes		**$69,648**	45
Operation and maintenance of CANARIE link		**$50,000**	99
Equivalent annualized cost of data centre (15 years)		**$859,428**	46
Equivalent annualized cost of power generating station (25 years)		**$626,836**	47
Total operations costs	**$508,711**	**$1,749,066**	48
Net (incremental) operations cost	**$(245,908)**		74

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Scenario 2: Operating costs		
Capital cost for relocating data centre to non-remote location	**$9,256,134**	39
Equivalent annualized cost of moving data centre (15 years)	**$835,420**	
Cost for electricity (assume location in Montreal, QC)	**$402,100**	80
Operation and maintenance of CANARIE link	**$21,600**	99
Total operations costs	**$1,259,120**	48
Net (incremental) operations cost	**$(85,011)**	74

Scenario 3: Operating costs		
Data centre construction cost for waste heat exchanger	**$150,000**	
Equivalent annualized cost of construction cost for waste heat exchanger (15 years)	**$13,538**	
Annual maintenance cost for heat exchanger	**$5,000**	
Annual cost of electricity for University	**$508,711**	
Total operations costs	**$513,711**	48
Net (incremental) operations cost	**$5,000**	74

Notes regarding relocation cost line items

1	Tier level (II, III, or IV)	According to Uptime Institute classification, as documented in white paper, "Tier Classifications Define Site Infrastructure Performance."
2	Number of racks	Racks installed and in use. Not all are filled 100 per cent.
3	Rack density (sq. ft.)	Number of square feet per rack in the active area. Includes space for CRAC, UPS, etc. (Active Area / Number Racks).
4	Power per rack (W)	Estimated power used at each rack.
5	Power per sq. ft. (W)	Total data centre power divided by active area square feet.
6	Power for IT equipment (kW)	kW input for IT critical equipment as measured at UPS. See Note #52.
7	Power for cooling (kW)	kW used for CRAC. According to Uptime Model for TCO (Total Cost of Ownership) of data centres, this should be 65 per cent of total IT load. See Note #53.
8	Power for lighting and other auxiliary use (kW)	kW for auxiliaries (UPS/PDU loss, lighting, other losses). Calculated using Uptime Model for TCO of data centres (35 per cent of IT Power).
10	Power Usage Effectiveness (PUE)	PUE is ratio (Total power into data centre / Power for IT critical load). Determines efficiency. Most data centres are 2.0 to 2.5. The best are 1.5 and less.
11	Total area (sq. ft.)	Square feet of building.
12	Active area (sq. ft.)	Space required using rack density. This space will contain IT equipment, UPS and CRACS.
13	Empty area (sq. ft.)	Space reserved for future expansion.
14	Cost of electricity at University ($/kWh)	Based on General Large Power Consumers (>5,000 kW), "Comparison of Electricity Prices in Major North American Cities, 2009," Hydro-Quebec. Converted from 2009 CAD to 2010 CAD with a factor of 0.9751, based on inflation over that period.
15	Cost of electricity in Montreal, QC ($/kWh)	Based on General Large Power Consumers (>5,000 kW), "Comparison of Electricity Prices in Major North American Cities, 2009," Hydro-Quebec. Converted from 2009 CAD to 2010 CAD with a factor of 0.9751, based on inflation over that period.
16	Power generation capital cost	
17	Power generation capacity (kW)	Total MW required for IT, cooling and auxiliaries, multiplied by 2 to ensure that enough power is generated during low water seasons. Value is rounded up to the nearest MW.
18	Transmission line length (m)	Distance between data centre and generating station.
19	Cost to build small hydro generating plant ($M/MW)	Based on ICF Integrated Planning Model Small Hydro—specific to the province. Inflation rate of 1USD = 6.23 per cent from 2006 to 2010 based on Bank of Canada.
20	Cost to build transmission line ($M/km)	115kV Double Circuit transmission line on tubular steel pole. The unit cost (per meter) assumes construction on a flat forested land, and includes an additional factor (1.5X) accounting for a distance of less than 10 miles (17 m). The unit cost includes the engineering and construction costs only. Source: www.caiso.com.
21	Yearly water rights and land taxes (% of all yearly costs)	Estimated from information provided by www.gilkes.com.

22	Operations and maintenance ($/kW/year)	Based on ICF Integrated Planning Model. Exchange rate of 1USD = 1.12CND and inflation rate of 6.23 per cent from 2006 is based on Bank of Canada information.
24	Total cost to build electrical generating station ($)	Calculated from cost per MW X power required.
25	Total cost to build transmission lines ($)	Calculated from cost per km X transmission length.
26	Total power generation investments	Transmission line and generation station.
28	Remote data centre building & infrastructure capital cost	
29	Data centre construction cost for each kW of IT (based on Tier)	Based on Uptime Institute white paper, "Cost Model Dollars per kW plus Dollars per Square Foot of Computer Floor."
30	Data centre construction cost for each sq. ft. active space	Based on Uptime Institute white paper, "Cost Model Dollars per kW plus Dollars per Square Foot of Computer Floor."
31	Data centre construction cost for each sq. ft. empty space	Based on Uptime Institute white paper, "Cost Model Dollars per kW plus Dollars per Square Foot of Computer Floor."
32	Data centre construction cost for waste heat exchanger	
33	Data centre building cost—with electrical, UPS, cooling, mechanical, etc.	(Power_for_IT X Cost_per_kW) + (Cost_active_area X Active_area) + (Cost_empty_area X Empty_area) + Cost of heat exchanger.
34	Cost of land and permits	Estimated at $10 per square foot of data centre space, plus 20 per cent for additional building and parking area.
35	Racking up, cabling, testing	Based on $3,000 per rack.
36	Project management: Configure and test applications	Manage and execute the transition of applications to the new data centre. Estimated at 1.5 Full Time Equivalent staff at $100k per year salary with all costs included.
37	Optical network to CANARIE	Estimated by CANARIE Inc. The remote scenario is based on hypothetical location 100 km north of Ottawa, assuming that some segments of the link are using existing dark fibre. Remote scenario costs can go as high as $3M depending on conditions. For urban setting, based on a quote for a dark fibre link connecting a data centre located 7 km from the Université de Montréal.
38	Total data centre capital investments	Total cost to build remote data centre including racking, permits, land, CANARIE network.
39	Total capital cost	The total capital cost outlay required for this scenario.
43	Electrical	Cost per kWh X (Power for IT + Power for Cooling + Power for auxiliaries) X 365 days X 24 hours.

44	Operation and maintenance of generating station	Yearly water rights and land taxes. Percentage of total yearly costs.
45	Yearly power generating station water rights and land taxes	Operating and maintaining the generating station based on kW per year.
46	Equivalent annualized cost of data centre (15 years)	Rate is based on Bank of Canada V122487 (Government of Canada average yield over 10 years; 06/2007–04/2010 = 4.05 per cent). Calculated for yearly periods for 15 years.
47	Equivalent annualized cost of power generating station (25 years)	Rate is based on Bank of Canada V122487 (Government of Canada average yield over 10 years; 06/2007–04/2010 = 4.05 per cent). Calculated for yearly periods for 25 years.
48	Total operations costs	The total annual operational cost required for this scenario.
52	IT equipment power consumption	Power consumption for IT equipment was determined from the data collection template, as completed by IT personnel at the University.
53	Cooling system power consumption	Power consumption for the cooling system was determined from the data collection template, as completed by IT personnel at the University.
72	Cost of building (urban)	Estimated at $38 per square foot of data centre space.
74	Net (incremental) operations cost	This represents the NET annual operating cost for the data centre (i.e., the new cost under the project condition to operate the data centre, minus the operational costs for the baseline data centre, in this case, grid electricity).
75	Capital cost—power generating station	The capital cost outlay for the power generating station (a small hydro plant). These assets are depreciated at a rate of 7 per cent.
76	Capital cost—IT assets	The capital cost outlay for the IT equipment (such as UPS, batteries, PDU, chillers, pumping, piping, cooling units, etc.). These assets are depreciated at a rate of 30 per cent.
77	Capital cost—building, Class 1, non-residential	The capital cost outlay for the construction of a building to house the data centre. These assets are depreciated at a rate of 6 per cent.
78	Labour & project management	Labour and project management fees that are not depreciated, as there is no asset associated with these costs.
79	Project management for installation of heat exchanger system	The cost for project managing the design and project management of the installation for a data centre heat exchange system with an existing heat loop.
80	Cost for electricity (assume location in Montreal QC)	The annual cost of the electricity that would be required to operate the data centre if located in the Province of Quebec.
99	Operation and maintenance of CANARIE link	Maintenance cost of the extension to the optical network from the data centre to the university. Based on estimates provided by CANARIE Inc.

Appendix F: Carbon credit analysis

Year	2013	2014	2015	2016	2017	2018	2019	2020
Projected price of carbon (2010 Real $)	$19.11	$23.88	$25.79	$27.70	$41.08	$44.90	$48.72	$52.54

University of Ottawa

Baseline emissions (tonnes CO_2e)		
Electricity for IT, cooling, auxiliary [A]	1,007	*A*
Natural gas based heating supply [B]	701	*B*
Net electricity generated by small hydro plant [C]	2,681	*C*

Project emissions		
Electricity for IT, cooling, auxiliary [D]	474	*D*
Electricity from Québec provincial electricity grid [E]	12	*E*

Scenario 1: Emission credits, remote renewable facility (Québec) [C-D]	
Annual	2,207
Lifetime	17,653

Scenario 2: Emission credits, low emission province [A+B-E]	
Annual	1,697
Lifetime	13,573

Scenario 3: Emission credits, waste heat fossil fuel displacement [B]	
Annual	701
Lifetime	5,612

Dalhousie University

Baseline emissions (tonnes CO$_2$e)		
Electricity for IT, cooling, auxiliary [A]	5,010	*A*
Natural gas based heating supply [B]	814	*B*
Net electricity generated by small hydro plant [C]	12,457	*C*

Project emissions		
Electricity for IT, cooling, auxiliary [D]	507	*D*
Electricity from Québec provincial electricity grid [E]	13	*E*

Scenario 1: Emission credits, remote renewable facility (Québec) [C-D]	
Annual	11,949
Lifetime	95,595

Scenario 2: Emission credits, low emission province [A+B-E]	
Annual	5,812
Lifetime	46,493

Scenario 3: Emission credits, waste heat fossil fuel displacement [B]	
Annual	814
Lifetime	6,511

University of Alberta

Baseline emissions (tonnes CO$_2$e)		
Electricity for IT, cooling, auxiliary [A]	5,288	*A*
Natural gas based heating supply [B]	2,198	*B*
Net electricity generated by small hydro plant [C]	10,218	*C*

Project emissions		
Electricity for IT, cooling, auxiliary [D]	655	*D*
Electricity from Québec provincial electricity grid [E]	16	*E*

Scenario 1: Emission credits, remote renewable facility (Québec) [C-D]	
Annual	9,563
Lifetime	76,502

Scenario 2: Emission credits, low emission province [A+B-E]	
Annual	7,470
Lifetime	59,759

Scenario 3: Emission credits, waste heat fossil fuel displacement [B]	
Annual	2,198
Lifetime	17,585

Appendix G: Summary of North American carbon market characteristics

Canada: Turning the Corner (TTC)	
Summary	Released in April 2007, Turning the Corner would impose intensity-based targets on covered industries to achieve an absolute reduction of 165 megatonnes in GHGs from a "business as usual" perspective by 2020.
Start date	2010.
Targets	Reduce absolute GHG emissions to 17 per cent below 2005 levels by 2020.
Caps	Intensity targets were initially proposed, but recent announcements make reference to setting caps for electricity generation. Moreover, political pressure for Ottawa to follow Washington's lead and establish absolute targets appears to be mounting. Intensity targets for "existing facilities" (defined as those operating in 2003 or earlier) face an emissions intensity target of 18 per cent improvement over 2006 levels by 2010. After 2010, a 2 per cent improvement per year target is applied.
Scope/sectors covered	Electricity generation produced by combustion, oil and gas, pulp and paper, iron and steel, smelting and refining, potash, lime, cement, chemicals and fertilizers. All six GHGs (carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, hydrofluorocarbons and perfluorocarbons) are covered.
Thresholds	50,000 tCO_2e per annum for chemicals, fertilizers and natural gas pipelines. Oil and gas facilities operating at 10 kt barrels per day. Electricity at 10 MW. All facilities in other covered sectors.
Reporting	Existing 100 kt threshold for all sectors. Covered entities are likely to be required to report through Section 71 of Canadian Environmental Protection Agency (CEPA).
Allowance and credit distribution	Method of allocation credits to be determined during the regulatory development process.

Credit for early action	15 megatonnes for all sectors and years combined, with a limit of 5 megatonnes per year over a 3-year period (2010–2012). Reductions made between 1992–2006 are eligible. Application program to determine credit entitlement.
Offsets	Offset system will issue credits for verified domestic reductions or removals of GHG emissions in activities outside the regulations. Up to 10 per cent of firms' compliance obligations can be met through credits (certified emission reductions, or CERs) from the CDM. Crediting date begins in 2011. Unlimited use of domestic offsets. Fast track now restricted to four project types (originally 40+ project types).
Industry transition support	Working with industry on Carbon Capture and Storage is a central focus of the five-year, $1 billion Clean Energy Fund. Proposes the use of a Technology Fund and precertified investments for industry to offset some emission reduction obligations.
Competitive issues	Unclear, given regulatory uncertainty.
Interaction with other GHG programs	It is unclear how obligations imposed under Turning the Corner would be affected if the United States implements Waxman-Markey or other cap-and-trade programs.
Other key provisions	N/A
Penalty for non-compliance	As it is suggested that Canada's plan would be administered under CEPA, it is possible that relevant legislation or regulations could include penalties for non-compliance. The issue of penalties is still under consideration.
Banking	Unclear, given regulatory uncertainty.
Allowance prices	Estimate #1: $25 (CAD$/tCO_2e) in 2010; $35 (CAD$/tCO_2e) in 2015; $65 (CAD$/tCO_2e) in 2020 (source: Environment Canada, 2008).
Electricity prices	Estimate #1: 4 per cent increase in electricity prices above business-as-usual by 2020 (source: Environment Canada, 2008).
GHG emissions	Estimate #1: 610 Mt in 2020 (source: Environment Canada, 2008).

Ontario: Climate Change Action Plan	
Summary	A multi-pronged strategy including provisions for cap-and-trade, phase-out of coal-fired electricity generation and the Green Energy Act. Plan anchored by province's commitments under the WCI.
Start date	2012.
Targets	Reduce absolute GHG emissions by 6 per cent below the 1990 level by 2014, 15 per cent below the 1990 level by 2020 and 80 per cent below the 1990 level by 2050.
Caps	Hard caps expected for companies in covered sectors.
Scope/sectors covered	Undetermined.
Thresholds	Undetermined.
Reporting	Undetermined.
Allowance and credit distribution	Undetermined.
Credit for early action	None proposed.
Offsets	Ontario is developing offset protocols for two sectors (forestry and agriculture). An agriculture pilot project is underway.

Industry transition support	Renewable Fuel Standard (RFS): Gasoline in Ontario requires an average of 5 per cent ethanol. The province's RFS is supported by a 12-year Ethanol Growth Fund (2005). Low Carbon Fuel Standard (LCFS): Ontario has pledged to develop an LCFS that would require a reduction of 10 per cent in carbon emissions from transportation fuels by 2020.
Competitive issues	Undetermined.
Interaction with other GHG programs	Ontario's system allows for linking to other systems in North America and abroad.
Other key provisions	Ontario's Green Energy Act received royal assent in May 2009. The Act consolidates new initiatives and enabling environment for renewable energy, including a feed-in tariff—as well as measures supporting energy conservation and energy efficiency and the creation of a smart grid in Ontario. The Act targets to double the amount of electricity from renewable sources by 2025.
Penalty for non-compliance	Undetermined.
Banking	Undetermined.
Allowance prices	None analyzed.
Electricity prices	None analyzed.
GHG emissions	None analyzed.

United States: Kerry–Lieberman Bill	
Summary	The bill is a comprehensive sector-based energy bill that aims to reduce US GHG emissions, spur clean technology development and enhance energy security. The bill provides for the establishment of a domestic cap-and-trade scheme.
Start date	Utilities (2013) and industry (2016) cap-and-trade with linked refinery cap (2013)
Targets	Capped sectors: 17 per cent below 2005 by 2020; 80 per cent below 2005 by 2050.
Caps	Absolute reduction targets.
Scope/sectors covered	Utilities (2013) and industry (2016).
Thresholds	25,000 tonnes CO_2e per year. Regional cap-and-trade pre-empted. The bill would establish coal-fired plant performance standards.
Reporting	Reporting to begin in 2012 for covered entities.
Allowance and credit distribution	TBD.
Credit for early action	For each of vintage years 2013 through 2015, 1 per cent of annual emission allowances would be distributed.
Offsets	Gratis allocations based 75 per cent on historical emissions.

Industry transition support	Free allowances proposed for "trade-exposed" industries. Carbon tariff proposed for imports from countries without comparable GHG reduction programs. Bill provides $70 billion in funding for clean transportation over ten years, extensive support for nuclear, natural gas vehicles, clean coal and support for renewables.
Competitive issues	Makes use of price collar between $12 and $25 per ton; floor increases at 3 per cent + CPI; ceiling at 5 per cent + CPI.
Interaction with other GHG programs	The bill would supersede regional initiatives such as the WCI. It establishes a "prohibition" on regional- and state-level GHG emission cap-and-trade programs.
Other key provisions	Prohibits derivatives, limits permit auction to covered emitters.
Penalty for non-compliance	Amount of emissions discrepancy multiplied by twice the auction clearing price, from the last auction conducted prior to the missed deadline.
Banking	Unlimited from forthcoming year's allowances.
Allowance prices	Undetermined.
Electricity prices	Undetermined.
GHG emissions	Undetermined.

Western Climate Initiative (WCI)	
Summary	The centerpiece of the WCI strategy is a regional cap-and-trade program. The WCI released the design of its program on 23 September 2008. When fully implemented in 2015, the program will cover an estimated 90 per cent of the GHG emissions in WCI states and provinces.
Start date	2012.
Targets	15 per cent regional economy-wide emission reduction goal from 2005 levels by 2020 (based on individual members' commitments).
Caps	Regional cap equalling the sum of partner jurisdictions' allowance budgets (declining over time).
Scope/sectors covered	For 2012: electricity generation and imports, large industrial and commercial combustion sources, industrial process emissions. For 2015: residential, commercial and industrial fuel combustion; transportation fuel combustion also included. All six GHGs (carbon dioxide, ethane, nitrous oxide, sulphur hexafluoride, hydrofluorocarbons and perfluorocarbons) are covered.
Thresholds	Installations that emit > 25,000 tCO_2e per annum.
Reporting	Reporting to begin in 2011. Applies to entities with annual emissions equal to, or greater than, 10,000 tCO_2e.
Allowance and credit distribution	Auction a minimum of 10 per cent of partner's allowance budget in first compliance period beginning in 2012, increasing to at least 25 per cent by 2020. Each WCI partner jurisdiction has discretion to auction a greater portion of its allowance budget as it sees fit. A portion of the revenue that each WCI partner receives through the auctioning of allowances must be dedicated to one or more of the following "public purposes": energy efficiency; carbon capture and storage research; emissions reductions in uncapped sectors (e.g., agriculture); human adaptation to climate change.

Offsets	No more than 49 per cent of the total emission reductions from 2012–2020. Each WCI partner jurisdiction will have the discretion to set a lower percentage limit. Proposes to accept domestic and CERs, which are generated through the Clean Development Mechanism under the Kyoto Protocol.
Industry transition support	Under the terms of the WCI agreement, it is possible that WCI partner jurisdictions will "standardize" the distribution of allowances to certain industries in an effort to address competitive impacts. Potential sectors where analysis to consider similar treatment is appropriate include those with a large proportion of process emissions, including aluminum, steel, cement, lime, pulp ad paper, oil refining and the electricity sector.
Competitive issues	The latest WCI work plan (dated 19 February 2009 but updated 23 June 2009) contains information on the latest efforts of the Complementary Policies Committee, which has essentially been tasked by the WCI with recommending policies to minimize the competitive impacts of WCI implementation. The focus of the committee is on sectors that could benefit from "harmonized" or "standardized" policies across the various jurisdictions encompassed by the WCI. As mentioned above, sectors for which harmonized policies might be appropriate include cement, lime, oil and gas.
Interaction with other GHG programs	It is unclear how WCI would be affected if the United States implements Waxman–Markey. Language in the WM bill suggests that WCI would be superseded by WM.
Other key provisions	Statement of Principles: The WCI partners will ensure that (i) Leakage of GHG emissions or production attributable to a regional cap-and-trade program to states or regions outside of the WCI Partner jurisdictions is minimized; (ii) Transitional challenges faced by entities from within covered sectors, who may be subject to disproportionate competitiveness risk under a regional cap-and-trade program , are addressed; (iii) An equitable and transparent process will be implemented, where all participants are afforded fair treatment and are accountable through clear roles and responsibilities when identifying potential competitiveness impacts attributable to a regional cap-and-trade program; (iv) A harmonized approach across WCI partners is considered when identifying and then addressing potential competitiveness risks that may arise due to a regional cap-and-trade program; (v) Entities from within covered sectors are afforded an opportunity to participate in the WCI competitiveness process to assess possible competitiveness risks; and (vi) Compensation is sufficient to prevent carbon leakage while still rewarding.

Penalty for non-compliance	A facility or entity that does not have sufficient emissions allowances to cover its emissions at the end of a compliance period faces a "penalty" of three allowances for each one they are short.
Banking	Purchasers and covered entities or facilities, and parties who otherwise obtain allowances, can bank allowances without limitation, except to the extent that restrictions on the number of allowances any one party may hold are necessary to prevent market manipulation.
Allowance prices	Estimate #1: $13 per tCO_2e in 2020; $48 per tCO_2e in 2020 (source: Design Recommendations for the WCI, 23 September 2008).
Electricity prices	Estimate #1: $25.27 ($2007/mmBtu) in 2010; $24.63 ($2007/mmBtu) in 2015; $28.63 ($2007/mmBtu) in 2020 (source: Design Recommendations for the WCI, 23 September 2008).
GHG emissions	Estimate #1: 861 $mmtCO_2e$ in 2020 (source: Design Recommendations for the WCI, 23 September 2008).