# ASSESSING THE BUSINESS CASE FOR DATA CENTRE RELOCATIONS

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# EXECUTIVE SUMMARY

Information and Communications Technology (ICT) is a large and growing contributor to the world's GHG emissions. Left unchecked, annual growth in this sector is expected to continue at 12%, as more and more computing resources and storage are required to support the move to a digital economy and the dematerialization of goods and services. Implicit in this growth is the additional demands for energy to run the storage and computing power systems (data centres). The challenge becomes one of meeting the increasing demand for technology, information storage, and computing power, while reducing the overall impact on the environment. CANARIE has recognized this challenge and is sponsoring research into the opportunities for green or carbon-neutral computing. This report seeks to address two questions:

- How can universities and other organizations create and maintain carbon neutral computing facilities that are cost-competitive and scalable?
- Should an organization or user move its servers (co-located or rented) to a low-carbon region, and can that move be financed through carbon offsets?

Six alternative scenarios for creating a carbon-neutral data centre were developed and evaluated using financial analysis and Net Present Value (NPV), as well as a life cycle assessment and GHG audit to factor in materials, construction, and use-phase emissions. Two key drivers emerged as critical factors for creating low-carbon computing; location and cost.

> Location - The electricity generation mix in Canada varies considerably from one province to the next, and the dirtiest region (Alberta) is over 70 times as GHG intense as the cleanest (Quebec). Location is therefore a key determinant of how clean or dirty a data centre's GHG emissions profile is. Data centres located in regions with access to renewable energy provide opportunities for the data centre to tap into the clean energy source, either by connecting to the regional electricity grid or through direct investment in renewable energy projects.
>
> Cost - Data centres and the required electrical supply and infrastructure constitute a significant capital investment. Large data centres require a significant amount of electricity, and can therefore justify investments in dedicated renewable energy projects and other forms of direct investment to secure clean electricity. Small data centres, including those evaluated in this report, are less able to justify and support large investments in renewable energy. These owners should therefore leverage

indirect investments in clean electricity to achieve carbon-neutrality, be it through Renewable Energy Credits (RECs) or premiums, or carbon offsets.

The recommendation, aimed at small and medium sized data centres, is to build in low-carbon regions where opportunities exist to tap into renewable energy sources. Data centres and any renewable energy sources should be connected to the region's electricity grid in order to manage variability and maximize investments. In this way, investments in renewable energy are spurred on by increasing regional demand while any new sources are connected to the regional grid.

The second question deals with existing data centre users (co-located) looking to achieve carbon-neutrality for their operations. Carbon offsets and credits offer opportunities for projects to receive financing to support projects that achieve carbon reductions, however the opportunity to use carbon financing and the decision of whether to move locations must be evaluated on a case-by-case basis. Overall it is recommended that data centres located in low to medium carbon-intensity regions should simply invest in RECs or carbon offsets rather than financing a relocation through carbon credits. Only those data centres that are currently located in dirty or high-carbon intensity areas have a significant opportunity to capitalize on carbon credit financing.

# 1.0 INTRODUCTION

The Information and Communications Technology (ICT) sector accounts for approximately 2% of greenhouse gas (GHG) emissions worldwide, and this figure is expected to double over the next 10 years as demand grows for IT products and services, and the dematerialization and digitization of the economy continues. As the world transitions further into the information (or digital) age, the need for information storage and computing resources will continue to grow at a rate estimated to be about 12%.[1] Implicit in this growth is the additional demands for energy to run the storage and computing power systems (data centres). At the same time that information and technology are proliferating, so too are concerns about diminishing natural resources and climate change. The challenge becomes one of meeting the increasing demand for technology, information storage, and computing power, while reducing the overall impact on the environment.

In response to this challenge, CANARIE, a national organization responsible for the management of advanced networking across Canada, has provided funding to support research into the environmental impact of data centres, and to consider financially feasible ways to mitigate the negative environmental impact associated with their energy consumption. This report analyzes the environmental impact of data centres, the opportunities to leverage carbon-financing markets to bring about change, and concludes with recommendations of the feasibility of data centre relocation projects in Canada.

[1] Cook, G., & Van Horn, J. (2011). *How dirty is your data? A look at the energy choices that power computing*. Retrieved from Greenpeace International website: http://www.greenpeace.org/international/en/news/features/New-Greenpeace-report-digs-up-the-dirt-on-Internet-data-centres/

# 2.0 METHODOLOGY & DELIVERABLES

The research upon which this report is based was broken down into four deliverables and developed using a case study approach applied to the ongoing data centre planning and implementation at the University of British Columbia (UBC). Stakeholders and users of the system were interviewed to gather needs requirements and feedback related to the proposed options. The data collected from the UBC data centre project was used as the basis for creating a hypothetical research-intensive data centre and the corresponding data centre relocation scenarios. Detailed reports were produced separately for each of the deliverables; only summary information has been included in this report where applicable.

Deliverables:

1. GHG Baseline of a Data Centre: Details the energy and GHG emissions associated with a data centre located in British Columbia and elsewhere in Canada.
2. Life Cycle Assessment of a Data Centre: Details the embodied GHG emissions involved in data centre and renewable energy construction projects.
3. Carbon Offset Potential: Discusses the opportunity to leverage carbon markets and financing to fund relocation efforts.
4. Feasibility, Business case for relocation: Provides analysis of the various scenarios related to carbon-neutral data centres, from both a financial and GHG emissions perspective.

# 3.0 BACKGROUND

The term 'green IT' is in widespread use, however its meaning is varied and evolving as our understanding of environmental impacts and the reach of IT is explored. In its early days, green IT represented the direct energy impacts of ICT equipment and an emphasis was placed on reducing energy consumption, usually achieved through energy efficiency. Power savers, energy star computers, and other tools are now common across the industry as organizations look to reduce their energy consumption from workstations, laptops, and other devices. Increasingly the term green IT refers not only to the direct environmental impacts of ICT equipment, but also the indirect, or enabling effects that ICT equipment can have in reducing environmental impacts in other sectors of the economy. The introduction of smart grids, smart buildings, and other improvements in energy consumption through the intelligent use of technology and information are some of the ways that ICT is enabling positive environmental change.[2] ICT and other technology solutions are also enabling a dematerialization of consumptive goods within the economy, thereby reducing the demands on finite resources. However this increasing dematerialization and digitization of goods and services puts increasing demand on ICT infrastructure and data centres. More servers and computing resources are required to support these information needs, resulting in an ever-increasing need for data centres and the energy needed to run them.

DATA CENTRES CAN BE LOCATED NEXT DOOR OR HALFWAY AROUND THE WORLD WITHOUT IMPACTING USERS WHICH ALLOWS THEM TO TAKE ADVANTAGE OF REGIONAL OPPORTUNITIES SUCH AS ACCESS TO RENEWABLE ELECTRICITY SOURCES.

Data centres have a very unique energy consumption profile. They consume a significant amount of energy in a relatively small area, and their physical location is de-coupled from their actual use. Given the connectivity between geographic regions, a data centre can be located next-door or half-way around the world with minimal user disruption and latency. This presents a unique opportunity in that data centres can be located to take advantage of regional opportunities, including access to clean and renewable electricity sources. Large IT companies such as Microsoft and Google have started taking advantage of this fact, locating their large data farms next to renewable energy, or to cooler climates to leverage free-cooling opportunities.[3] It is anticipated that a migration of large data centres to renewable energy areas will occur over time, as pressures mount for IT infrastructure to reduce its environmental impact and a price on carbon emissions is included in decision-making.

[2] The Climate Group on behalf of the Global eSustainability Initiative. (2008). *Enabling the low-carbon economy in the information age*. Retrieved from the Smart 2020 website: http://www.smart2020.org/publications/

[3] *The Economist.* (2008, May 22). Down on the farm. Retrieved from: http://www.economist.com/node/11413148?story_id=11413148

# 4.0 PROBLEM STATEMENT

This report and research focuses on two questions meant to highlight the key decisions that data centre users and owners are facing. The two questions address different stakeholder perspectives. Question 1 is meant to help data centre owners and developers determine how to create a carbon neutral facility, and question 2 addresses whether a data centre user should choose to relocate to a carbon neutral facility (co-location).

Q1: HOW CAN UNIVERSITIES AND OTHER ORGANIZATIONS CREATE AND MAINTAIN CARBON NEUTRAL COMPUTING FACILITIES THAT ARE COST-COMPETITIVE AND SCALABLE?

Q2: SHOULD AN ORGANIZATION OR USER MOVE ITS SERVERS (CO-LOCATED OR RENTED) TO A LOW-CARBON REGION, AND CAN THAT MOVE BE FINANCED THROUGH CARBON OFFSETS?

Universities and other organizations have a rapidly growing need for computing power, information storage and the resulting energy demand needed to support these functions. Many of these same organizations have environmental goals and/or GHG emissions targets. The challenge this poses is how does an organization tackle both issues. In other words, how can one offer computing power, storage, and research capabilities, in a scalable way, without negatively impacting the environment. More importantly, how can this issue be tackled while adhering to financial objectives and constrained financial resources? Given these financial constraints, alternative forms of financing, meant to shift behaviour patterns of both businesses and individuals, are being considered as viable funding mechanisms for creating green computing resources. Carbon offset mechanisms have the potential to increase available financing, since they can be used to finance projects with measureable and direct GHG emissions. This report provides an answer to the question, 'Can carbon offsets be used to finance a data centre relocation project?'

# 5.0 PROPOSED SOLUTION

Given that the ICT industry produces approximately 2% of the world's GHG emissions, and this figure is growing rapidly, the ICT industry has recognized the need to stem the growth of energy inputs. Energy efficiency improvements alone won't fully address the issue of GHG emissions and climate change, since even as energy improvements are made the absolute growth of the industry is continuing, thereby negating any savings in energy and GHG emissions. CANARIE recognizes this challenge and through its Green IT program has proposed the concept of zero or carbon-neutral computing. The result would be data centres and computing resources that, regardless of size, would produce zero GHG emissions during their operations.

This report proposes that a solution to creating carbon neutral data centres exists; a scenario that is cost-effective while achieving the results of carbon neutrality. This scenario is comprised of a data centre, connected to the main electricity grid, that purchases green energy premiums (renewable energy credits) that are directly invested into renewable energy sources. Renewable energy credits, similar to carbon offsets, can represent both good and bad investments. Diligence must be paid to ensure that the renewable energy credits are benefiting renewable energy producers directly, ultimately leading to the replacement of dirty sources of electricity with clean ones. These recommendations apply to small and medium sized data centres, given that the size of the case study data centre was 4MW; large-scale data centres may choose to consider alternatives not considered in the scenarios analysis.

# 6.0 ALTERNATIVE SCENARIOS

Six scenarios were developed in order to compare the existing scenario and five alternatives across both financial and environmental constraints. Scenarios 1 and 2 were developed for UBC, a University that has been considering the consolidation of its computing resources into one facility on campus. As such, some costs and considerations that would normally be born by a private organization (land acquisition, taxes, etc) are not included in scenarios 1 and 2. All scenarios achieve carbon neutrality through either the purchase of renewable energy credits, charged by the kwh (scenarios 1,2,3), or through the direct consumption of renewable energy (scenarios 4,4a,4b).

1. Business As Usual, UBC (Base case): Reviews the cost and GHG emissions of the existing facilities at the University of British Columbia.
2. Consolidated, UBC: Considers a consolidated data centre at UBC with some opportunities for re-using waste heat.
3. Relocation to On-Grid Data Centre (recommended scenario): Investigates the creation of a data centre with separate investment in renewable energy.
4. Relocation to Remote Off-grid Data Centre: Scenario considers remote data centre; connected to renewable energy source.
5. Relocation to Multiple Remote Off-grid Data Centre: Scenario considers multiple data centres, connected to renewable energy sources. Resources are duplicated for each site.
6. Relocation to On-Grid Data Centre with Renewable Energy: Scenario considers one data centre and one renewable energy project, both of which are connected to a regional electricity grid.

## 6.1 BUSINESS AS USUAL: UBC

The Business As Usual scenario represents a base case for comparison, and consists of continuing the existing data centre operations on the University of British Columbia's main campus for five years, followed by the construction of a new data centre. In effect this scenario represents a deferment of capital expenses rather than a do-nothing scenario, which is unrealistic given the expected growth in data centre needs, both at UBC and elsewhere. The current data centre capacity is distributed across the campus and comprises varying sized facilities. The largest facility, in terms of power usage, is in the Klinck building and houses WestGrid 1, a high performance computing cluster used by researchers across Western Canada. Other facilities range in energy use and design, including some server rooms that have been converted from closets. This scenario involves upgrading and maintaining existing data centre sites for a period of 4 years, with a subsequent design and build of a 4 MW data centre, built in incremental stages. Carbon neutrality, a requirement for the University, will be achieved either through renewable energy credits (RECs) or through carbon offsets.

## 6.2 CONSOLIDATED: UBC

This scenario details the consolidation of all UBC computing facilities into a newly constructed 4MW data centre, located on campus. Given that the servers would be consolidated into one location, it presents the opportunity to capture and re-use the waste heat for heating buildings nearby. This waste heat could be captured and would provide approximately 2.3 MW of heat. The energy consumption is expected to decline from scenario 1 to scenario 2, as the Power Usage Effectiveness (PUE)[4] of the consolidated data centre will be lower than the existing facilities (scenario 1). As in scenario 1, carbon neutrality will be achieved either through renewable energy credits (RECs) or through carbon offsets.

## 6.3 RELOCATION TO ON-GRID CENTRE: RECOMMENDED

This scenario will consider the creation of a data centre, located strategically on the electricity grid, which will allow for the 'purchase' of renewable energy either as a percentage of total electricity purchased (direct purchase or investment) or as renewable energy credits (RECs). Companies such as Bullfrog Power (www.bullfrogpower.com) allow their customers to pay a premium price for clean renewable energy from wind and hydro sources. For any electricity that is used by the consumer, Bullfrog Power injects the equivalent amount of electricity into the grid from one of its renewable sources, effectively making the energy used by the consumer 'green' and low-carbon. This allows the consumers to invest in renewable energy, regardless of location. Simple waste heat re-use will be considered, but only insofar as it is possible given the location and other factors.

## 6.4 RELOCATION TO OFF-GRID REMOTE

This scenario considers the consolidation of data centre capacity to a remote off-grid location, and proposes the creation of a data centre connected directly to a source of renewable energy, sized to meet the data centre's energy needs. The data centre is connected to the communication grid via installed fibre optic lines, and is not connected to the regional electricity grid. Given the intermittency of some forms of renewable energy and potential variability, additional sub-scenarios that include either energy storage or multiple forms of renewable energy sources should also be considered (covered by 4a and 4b). Carbon neutrality is achieved through the direct consumption of renewable energy. Costs include capital and operating expenses for one data centre and one renewable energy source (hydropower).

### 6.4.1 RELOCATION TO MULTIPLE OFF-GRID REMOTE

This scenario builds on scenario 4 by creating a network of data centres, used in rotation, based on the availability of power at each site. The creation of a 'network' of data centre nodes would allow each energy source to be used when available and aggregates some of the variability and intermittency of renewable energy sources. The objective of this scenario is to create a zero-carbon network of data centres. A sample size of three networked data centres has been

[4] Power Usage Effectiveness (PUE) is a measurement of how much energy is delivered to the data centre relative to how much energy is required for powering the computing equipment. The intent is to show how efficiently energy is being used for IT equipment vs ancillary systems such as cooling, HVAC and lighting.

calculated in the costs and includes the renewable energy projects needed to supply each site, as well as the data transmission lines to connect each site to the network.

### 6.4.2 RELOCATION TO ON-GRID REMOTE

This scenario also builds on scenario 4 and the issues of intermittency by connecting the data centre and renewable energy source to the regional electricity grid, allowing for a continuous supply of energy from either the renewable energy source or the regional grid. Costs for the data centre, renewable energy project, and electric transmissions lines have been included.

# 7.0 MEASURING THE DATA CENTRE'S GHG EMISSIONS

Understanding an organization or data centre's annual GHG emissions, or carbon footprint, is the necessary first step to becoming carbon neutral. Referred to more commonly as carbon accounting, or GHG accounting, it is the process of measuring, tracking, and reporting an organization's GHG emissions for all direct and indirect fossil fuel consumption. Several protocols for undertaking this measurement have been developed, notably the Greenhouse Gas Protocol (www.ghgprotocol.org/), one of the most widely accepted standards. Another common standard is ISO 14064, which is cross-compatible (http://www.iso.org/iso/pressrelease.htm?refid=Ref1093). GHG emissions fall into one of three categories: scope 1 are all emissions from direct fossil fuel sources, such as diesel and gasoline; scope 2 are all indirect sources of emissions from electricity, and scope 3 captures everything else, encompassing emissions from up and down stream suppliers. A data centre's emissions come primarily from scope 2, electricity consumption, and also from upstream suppliers of technology equipment.

## 7.1 REGIONAL VARIATION WITHIN CANADA

The electricity generation mix of a given region is a key determinant of a data centre's GHG footprint. A data centre located in a region supplied primarily by coal power plants will produce significantly more GHG emissions from its electricity consumption than a data centre located in a region with renewable energy sources. The electricity generation mix in Canada varies considerably from one province to the next; the dirtiest is over 70 times as GHG intense as the cleanest. While all grids support one another and, to some extent, it can be argued that we all share one North American grid, common practice is to match GHG emissions for electricity consumption to one's provincial generation mix (Canada) or regional grid (USA). It is important to note that regional emission factors, the amount of GHG emitted per kWh of electricity generated, change over time as areas bring on new sources of power or shut down old plants. Figure 1 demonstrates this variability across provinces. Data centres in Alberta or Nova Scotia will produce significantly more GHG emissions from electricity consumption than similar organizations in Quebec or British Columbia. Understanding the electricity mix and available renewable sources of a region is a critical decision factor when determining where to locate data centres or any other large energy consumer.

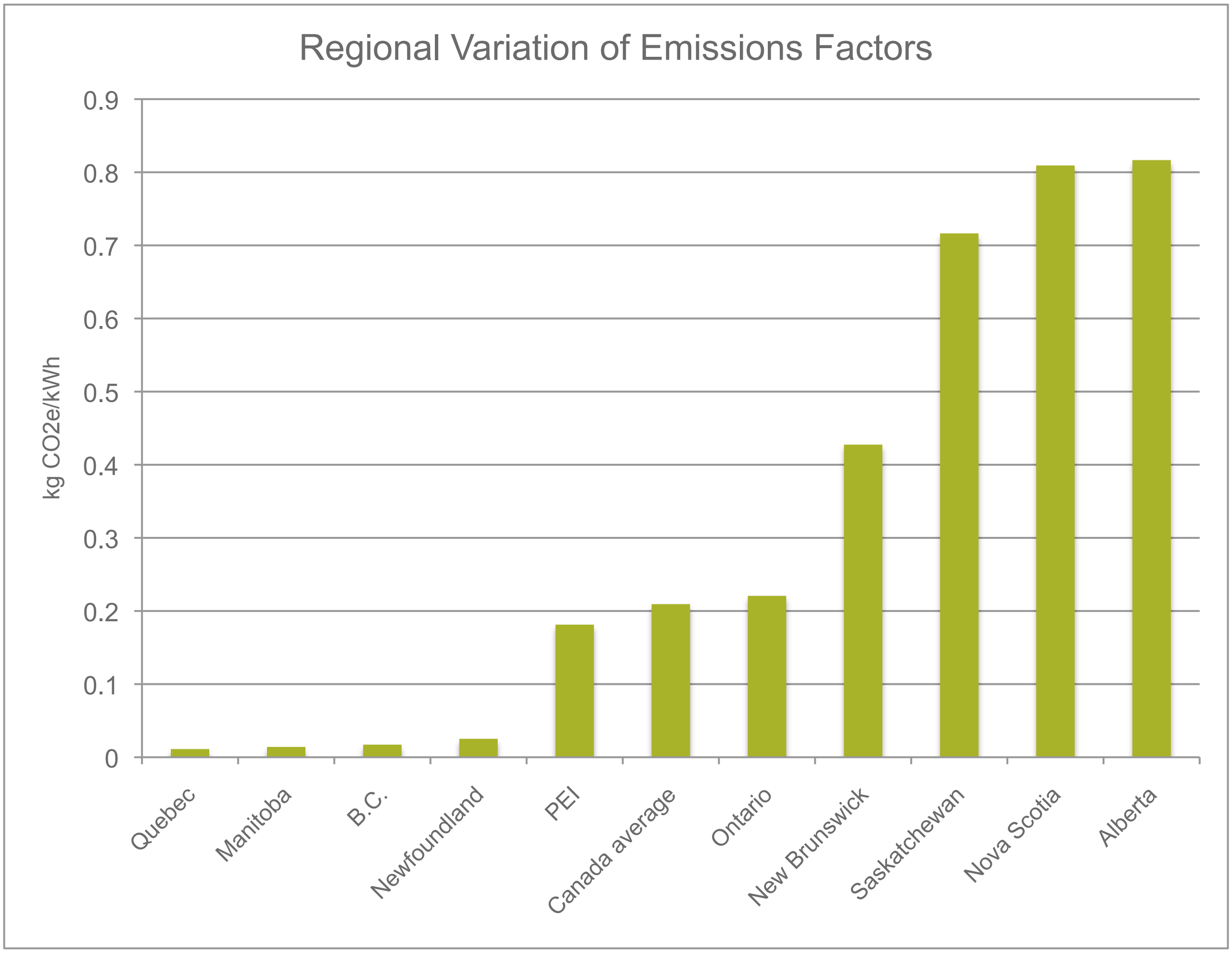


Figure 1: Regional Variation of Electricity Emissions Factors

## 7.2 CASE STUDY

The University of British Columbia's data centres were used to develop the case study for this report's GHG measurements, as data was easily accessible and a process to measure IT energy consumption was partially underway at the time of the project initiation. UBC has developed a distributed and somewhat ad-hoc system of delivering data centre services across the campus since the needs of faculty and researchers outstripped the available supply of data centre space. As existing space on campus filled up, small 'data centres' have sprung up to meet the various needs of researchers and staff. Servers can be found in a variety of areas, including closets that have been converted for their new use. To determine the number of servers and their locations, surveys and questionnaires were conducted by UBC Facilities & Capital Planning and Facilities, revealing a total of 77 sites on campus. Energy use was calculated for a one-year period by measuring the largest 44 sites and extrapolating the data to all 77 sites. This energy use was then calculated for all scenarios using three representative, Canadian provincial emission intensities.[5]

[5] McDonald, M. (2011). *GHG emissions and carbon offset potential.* Offsetters Clean Technology, Vancouver.

| CATEGORY | EMISSION INTENSITY RANGE (KG CO2E/KWH) | REPRESENTATIVE PROVINCE AND EMISSION INTENSITY |
|---|---|---|
| Low | 0 to 0.1 | B.C. (0.0172) |
| Medium | 0.1 to 0.5 | Ontario (0.2207) |
| High | 0.5 and above | Alberta (0.8166) |

Figure 2: Emissions Factors by Intensity

The various intensities when applied to the four alternative scenarios, demonstrate the annual GHG emissions from electricity consumption of a data centre located in each of the 3 regions. Table 2 outlines the expected annual GHG emissions for each of the scenarios across regions. Note that while scenario 3 will produce GHG emissions, the scenario also includes finances to purchase green energy premiums (renewable energy credits) to net out the emissions. The wide variation between regions highlights the impact that site selection of a data centre has on its GHG emissions.

| GHG EMISSIONS INTENSITY | SCENARIO 1 | SCENARIO 2 | SCENARIO 3 | | | SCENARIO 4 [6] |
|---|---|---|---|---|---|---|
| | tonnes CO2e | tonnes CO2e | *tonnes CO2e* | *Less carbon offsets* | Total | tonnes CO2e |
| Low | 362 | 316 | *316* | *-316* | 0 | 0 |
| Medium | 4,640 | 4,060 | *4,060* | *-4,060* | 0 | 0 |
| High | 17,168 | 15,022 | *15,022* | *-15,022* | 0 | 0 |

Figure 3: Data Centre Annual GHG Emission Profile

[6] GHG Emissions are emitted from annual operations and maintenance of renewable energy projects, however this data was difficult to isolate and therefore 0 emissions have been assumed.

# 8.0 LIFE CYCLE ASSESSMENT OF A DATA CENTRE

Focusing on the operational energy consumption and resulting emissions alone does not provide a complete picture of the environmental impact of a data centre. The preceding section details the energy and subsequent GHG emissions emitted from the operations of a data centre, which consist largely of emissions from electricity consumption. Yet consideration also needs to be given to other aspects of the data centre's life such as the construction and renewal phases, as well as the decommissioning of the building and any equipment. Taking a more holistic view of the energy inputs at all phases of the data centre's life cycle will ensure that the true impact is acknowledged and measured. This report addresses this by reviewing all energy inputs from material extraction through to construction and use. This report does not, however, address other ecosystem impacts and biodiversity issues created by new buildings and infrastructure. While they are important environmental concerns related to a construction project, they have not been measured or included with this study.

OPERATIONAL ENERGY CONSUMPTION AND ITS RESULTING GHG EMISSIONS DO NOT PROVIDE A COMPLETE PICTURE OF THE ENVIRONMENTAL IMPACT OF A DATA CENTRE. CONSIDERATION MUST ALSO BE PAID TO THE FULL LIFE CYCLE, INCLUDING THE EMBODIED EMISSIONS IN MATERIALS AND CONSTRUCTION.

The methodology for conducting this holistic review of energy, known as a Life Cycle Assessment (LCA) or Cradle-to-Grave, assesses the energy consumed from the initial construction phase through to the end of life or disposal phase. Included in this assessment are the energy requirements to extract and manufacture any raw materials, the energy required to transport the materials and construct the building, and the energy requirements to tear down and dispose of any materials during the decommissioning phase. The GHG Protocol Initiative (www.ghgprotocol.org) has released a draft version of standard guidelines for the development of Life Cycle Assessments (Draft November 2009 'Life Cycle Standard'), which were followed in this report.


Figure 4: Cradle to Grave Cycle

Offsetters Clean Technology performed the comprehensive Life Cycle Assessment[7] of various components of the proposed research concept to assess the full impact of the various scenarios to be considered. The embodied GHG emissions associated with building materials and construction were evaluated for the following components: (The full report is available separately for download.)

- Renewable Energy Sources, including wind, solar, and geothermal energy projects
- Data Centres, for both building shell (measured per square ft) and equipment (measured per MW)
- Fibre and electrical transmission lines, materials and deployment, represented per km

## 8.1 DATA CENTRE LCA ANALYSIS

The details prepared in the Offsetters report have been used to develop life cycle assessments for each of the scenarios defined (Table 2). Scenarios 1, 2 and 3 involve the construction of a data centre with associated total GHG emissions of 1445, 1445, and 2200 tonnes of CO2e, respectively. Scenario 4 involves the production of approximately 6000 tonnes of CO2e, due largely to the additional infrastructure required because of the rural location. Building a renewable energy plant produces an additional 2000 to 5000 tonnes of CO2e, depending on the type. Both scenarios 3 and 4 are demonstrated with and without the embodied emissions from the renewable energy project.

IF A DATA CENTRE FROM A REGION OF LOW-EMISSIONS INTENSITY RELOCATED TO THE MULTIPLE CARBON NEUTRAL FACILITIES REPRESENTED BY SCENARIO 4A, THE EMBODIED EMISSIONS FROM CONSTRUCTION MIGHT NEVER BE ‘OFFSET’ OR NETTED OUT.

It is important to note that some or all of these emissions can be ‘offset’ by the positive impacts of creating a carbon neutral data centre, but only when the alternative choice would have been to locate the data centre in a high-carbon area such as Alberta. Scenario 4a involves the construction of a network of data centres in multiple locations across the country, and represents the most carbon intensive scenario. Each data centre and renewable energy project produces approximately 8000 tonnes of CO2e during the materials extraction and construction. If a data centre from British Columbia (a region of low emission intensity) were to relocate into a new carbon-neutral data centre, the savings from electrical energy use (360 tonnes of CO2e annually) would take over 20 years to offset the GHG emissions (8000 tonnes of CO2e) emitted during its construction phase. This example highlights the important role that a life cycle assessment has on decision-making and calculating the true environmental benefit or cost of constructing new, green infrastructure.

[7] Note: This section (Deliverable 2) outlines key outcomes of the report, however the full report is available for review.

# 9.0 CARBON OFFSET POTENTIAL

One of the key objectives laid out by CANARIE was to investigate the role that carbon offsets can play in financing green IT infrastructure, in particular a data centre relocation. Offsetters Clean Technology was engaged as a partner to identify the opportunities for carbon offsets, and provide details on how offsets could be generated from a data centre relocation. The full report is available for download, however a brief overview is presented here.

Data centre relocation projects may be eligible for carbon offset funding assuming a certain GHG reduction threshold is achieved, and the proposed project adheres to the following three criteria:

- The reductions are real—resulting in measurable, verifiable emission reductions;
- The reductions are permanent—the emission reductions must not be reversible; and
- The reductions are additional—the sale of the carbon reductions must help to overcome financial and/or technical barriers that would otherwise threaten the viability of the project.

The amount of carbon offset funding available to a relocation project is primarily based on two factors; where the data centre is currently located, and to where it is moving. A data centre relocation from a low carbon area to another low-carbon area will generate very little carbon offset funding. For example, relocating the business-as-usual UBC data centre to an on-grid renewable energy data centre elsewhere in British Columbia will generate 6000 tonnes of CO2e savings over ten years, or approximately $60,000 in funding; not enough to finance the relocation. However the same data centre, if relocating from Alberta (high emissions intensity area) to British Columbia (low emissions intensity area), could generate roughly $2,500,000 in relocation funding.

# 10.0 ANALYSIS

The four alternative scenarios identified have been evaluated using a cost benefit analysis (CBA) approach and a life cycle assessment (LCA), providing decision-makers with the necessary tools to evaluate options on both monetary and environmental parameters. A CBA monetizes all relevant costs and benefits, and calculates a net present value (NPV) for each scenario. Generally the scenario with the highest NPV is selected. The life cycle assessment (LCA) takes a holistic view of the GHG emissions of a given project, and measures GHG emissions for the entire life of the data centre, from materials use, construction, through to its end use. The following section details cost considerations, assumptions made, and the results pertaining to the stakeholder assessment, CBA, and LCA.

## 10.1 SCHEDULE OF COSTS

### Construction Costs of Data Centre

Construction costs for the data centres were derived from analysis done by Uptime Institute (*www.**uptimeinstitute**.org)*, as well as cross-referenced with known costs from previous UBC data centre projects. Uptime Institute publishes a well-known tool called 'True Total Cost of Ownership' for data centre projects, and breaks down the capital, operating, and other costs. Appendix C contains the TCO model used for developing costs for each scenario.

### Staffing Costs

Staffing costs were derived from existing known resource needs for UBC's data centre and include salary and benefit figures. While staff costs may be slightly lower in rural areas, this gain will be offset by the increased costs in staff recruitment and retention. Corporate IT costs decreased by 4% from more urban to remote settings in Canada.[8]

### Electricity Costs

Electricity prices vary across Canada and are dependant on the type of electricity generation that a given jurisdiction uses. Nuclear power is one of the most expensive forms of electricity, while hydroelectricity is one of the cheapest. Across Canada rates vary between $0.06 and $0.16. For the purpose of this study an average rate of $0.08 has been used. For those data centres that are located remotely and are not connected to the grid (Scenario 4), electricity cost is equivalent to operating and maintenance (O&M) costs for a given renewable energy facility. An average figure of 0.02/kWh (0.01/kwh for hydro, 0.0027/kwh for wind) was used for electricity costs (O&M costs) for remote off-grid scenarios.

### Data Centre Operating & Maintenance (O&M) Costs

Operating and maintenance costs, excluding electricity costs (see above) were calculated from known costs for UBC's data centre, plus additional estimates.

[8] KPMG. (2010). *Competitive alternatives – city profiles* (Comparing Vancouver to Prince George, Corporate and IT services). Retrieved from: http://www.competitivealternatives.com/cityprofiles/

### Relocation Costs

Relocation costs were derived from a published study by Info-tech Group; average per rack cost for relocation is $10,000.[9] Total relocation expenses, at $10,000/rack for 200 racks, are $2,000,000.

### IT Growth

Various projections place the annual growth rate of IT infrastructure at between 5 and 10 percent. For all scenarios the annual compound rate of 7 percent has been used, equivalent to the growth rate published in Smart 2020, a report produced by the Global e-Sustainability Initiative.[10] The US EPA also published growth trends for data centres in the US, indicating that the compound annual growth rate for data centres for the 10 years ending in 2010 is 11 percent.[11] The lower number of 7 percent has been selected due to delayed or slower investments in IT that are typically seen with educational institutions.

### Green Energy Premiums/Renewable Energy Credits

Green energy premiums allow an individual or organization to pay an additional price per kWh for electricity to ensure that their electrical generation source is green, or carbon neutral. Bullfrog Power (www.bullfrogpower.com) is the industry leader and offers 'green' electricity throughout most of Canada at $0.02 – 0.03/kWh. Scenario 3 includes this green energy premium as a cost to ensure that the electricity source used is carbon neutral, in lieu of investing in dedicated renewable energy infrastructure.

### Carbon Credit Value

Projects that meet the requirements for a valid carbon offset project,[12] have the opportunity to sell the carbon credits through various voluntary or regulated carbon markets. While prices fluctuate across markets and over time, an average price of $10/tonne of CO2e has been used. In all scenarios where the possibility of generating and selling carbon credits exists (scenario 3 and 4), a best-case scenario has been used, representing a data centre relocation from a high carbon area (Alberta) to a carbon-neutral facility. A 4 MW data centre would generate approximately 28,600 tonnes of CO2e per year, equaling $2,500,000 in carbon credits over 10 years (average life of carbon credit projects), and assuming incremental rollout from 2 to 4 MW over 10 years in line with growth.

### Power Usage Effectiveness (PUE)

A PUE of 2.0 has been assumed for all scenarios, though it is expected that data centres can reasonably achieve lower PUEs using available state-of-the-art technology and expertise. This figure is based on benchmarking studies done by Lawrence Berkeley National Laboratory, and is oft-cited.[13]

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[9] InfoTech Group. (2010). *Data Centre Relocation Budget Tool*. Retrieved from: http://www.infotech.com/research/data-center-relocation-budget-tool

[10] The Climate Group on behalf of the Global eSustainability Initiative. (2008). *Enabling the low-carbon economy in the information age*. Retrieved from the Smart 2020 website: http://www.smart2020.org/publications/

[11] U.S. Environmental Protection Agency - ENERGY STAR Program. (2007). *Report to Congress on server and data center energy efficiency - Public Law 109-431*. Retrieved from: http://www.energystar.gov/ia/partners/prod_development/downloads/EPA_Datacenter_Report_Congress_Final1.pdf

[12] McDonald, M. (2011). *GHG Emissions and Carbon Offset Potential.* Offsetters Clean Technology, Vancouver.

[13] Greenberg, S., Mills, E., & Tschudi, B. (2006). *Best Practices for Data Centres: Lessons Learned from Benchmarking 22 Data Centres.* Retrieved from Lawrence Berkely National Laboratory: http://*evanmills.lbl.gov/pubs/pdf/aceee-**datacenters**.pdf*

### Social Cost of Carbon (SCC)

The social cost of carbon assigns a value to the impacts that each tonne of GHG emissions from a given project has on climate change. There are differences as to the appropriate figure to use, however most published reports estimate the cost of carbon to be between $30 - $125/tCO2e. This report will use an estimate of $83/tCO2e.[14]

## 10.2 LIFE CYCLE ASSESSMENT

Figure 5 revisits the life cycle assessment values, and summarizes the embodied GHG emissions associated with each of the alternatives. As one would expect, embodied emissions increases as the amount of infrastructure increases. The LCA data, while not used as a tool for decision-making in this report, provides additional information about potential decisions and their impacts. In particular the LCA data highlights the GHG emissions produced during non-use phases of the data centre.

The results of the LCA have been included in the financial analysis by way of a social cost of carbon (SCC), which monetizes the current and future impacts of climate change due to the production of GHG emissions and resulting increase in atmospheric levels. The intent is to include the external costs of emitting GHG emissions, and may shift decision-making to lower-carbon alternatives. To give an example, using scenario 3 below and a social cost of carbon of $83/tCO2e, the additional cost of carbon for scenario 3 is $184,000. In the financial models for all scenarios (summarized in Table 4), the cost of carbon was calculated and recorded as an expense in year one, however it was not large enough to change the outcome or decision.

| | SCENARIO 1 | SCENARIO 2 | SCENARIO 3 | SCENARIO 4 | SCENARIO 4A[15] | SCENARIO 4B |
|---|---|---|---|---|---|---|
| Emission Sources | | | | | | |
| Building Materials | 614 | 614 | 614 | 614 | 1842 | 614 |
| Data Centre Materials (computers, racks, cabling)[16] | 770 | 770 | 1540 | 1540 | 4620 | 1540 |
| Construction Activities, Transportation | 61 | 61 | 61 | 136 | 408 | 61 |
| Fibre Optic lines (materials) | 0 | 0 | | 150 | 450 | 0 |
| Fibre Optic lines (installation) | 0 | 0 | | 3450 | 10,350 | 0 |
| **Subtotal embodied emissions** | **1445** | **1445** | **2215** | **5890** | **17670** | **2215** |
| Electrical Transmission | | | | | | 17,325 |
| Renewable Energy Const. | | | | 5268 | 11,930 | 2976 |
| **Total embodied emissions w/ Renewable Energy** | **1,445** | **1,445** | **2,215** | **9,618** | **24,980** | **22,516** |

Figure 5: Summary of Life Cycle Analysis[17]

[14] UK Government, Department of Energy and Climate Change. (2009). *Carbon valuation in UK policy appraisal: A revised approach*. Retrieved from: http://www.decc.gov.uk/en/content/cms/what_we_do/lc_uk/valuation/valuation.aspx

[15] Scenario 4a: 3 data centres located next to renewable energy through Canada (one of each: hydro, wind and solar PV)

[16] 770 per installed MW: assumed some equipment would be migrated, others replace

[17] Assumption: 20,000 sq.ft. 2 MW installed

## 10.3 FINANCIAL ASSESSMENT

Financial models were developed for each of the six scenarios, and Table 4 summarizes the details. The full analysis and sensitivity can be found in Appendix E. Total capital and operating expenses are shown for each scenario, in nominal values, as well as the Net Present Value (NPV) of each scenario. The As-is (scenario 1) and Consolidation (scenario 2) scenarios are applicable for UBC's decisions regarding future data centre projects. It is Scenarios 3, 4, 4a, and 4b that are most relevant for a broader audience.

Scenarios 1, 2, and 3 contain the capital and operating expenses, some of which are outlined above, for one data centre, as well as the costs incurred annually to ensure carbon neutrality through the purchase of renewable energy credits (RECs). Scenarios 4, 4a, and 4b include the capital and operating expenses for the data centre(s) as well as one or more hydroelectric plants. Average capital and operating costs were taken from the US Energy Information Administration (www.eia.doe.gov) and the International Energy Agency (www.iea.org).

It is important to note that Scenario 4 is a best case (unrealistic) figure since the issue of intermittency must also be considered, either by replicating data centres and/or renewable energy sites, or by incorporating energy storage into the model. In either case, this would increase the NPV substantially, making it a distant possibility for small to medium sized data centres. Scenario 4b has been included to illustrate a scenario when electricity transmission lines are included in the capital costs for a renewable energy project. Electricity transmission lines are very capital intensive, and only make economic sense for larger renewable energy projects.

| SCENARIO | 1: AS-IS | 2: CONSOLIDATION | 3: OFFSITE CITY | 4: REMOTE SITE | 4A: REMOTE SITE, DUPLICATED | 4B: REMOTE SITE, ON-GRID |
|---|---|---|---|---|---|---|
| Total Capital Expenses[18] | 42,950,000 | 39,935,000 | 44,735,000 | 72,235,000 | 216,705,000 | 402,235,000 |
| Total Operating Expenses[18] | 62,186,262 | 56,651,857 | 54,476,554 | 31,002,063 | 93,006,189 | 31,672,597 |
| Net Present Value | ($73,186,448) | ($73,737,977) | ($77,243,726) | ($86,849,794) | ($260,549,382) | ($387,588,191) |

Figure 6: Summary Cost- Benefit Analysis (CBA)

## 10.4 STAKEHOLDER NEEDS ASSESSMENT

Part of the data collected for the cost-benefit-analysis involved identifying the stakeholders that would be affected by a data centre relocation, and understanding the impacts to their work and duties. A number of research staff, support personnel, and professors were interviewed over the month of March 2010, resulting in a collection of needs and constraints related to the concept of a remote data centre location. Information was also taken from previous stakeholder assessments.[19] The following summarizes the main drivers and constraints of a relocation project, from the perspective of research staff. While the assessment does not impact costs directly, its results need to be considered

[18] Represented as nominal values

[19] Gladman, B. (2009). *Constraints on location and cost recovery for UBC's HPC research needs*. Vancouver, Canada.

alongside the financial and environmental factors in determining final location decisions. Full notes from each session are included in the appendices.

| SUMMARY | DESCRIPTION |
|---|---|
| Physical Access | Physical access to the equipment is infrequently required to swap or fix hardware. |
| Bandwidth | Bandwidth and throughput are critically important in a significant number of research projects. |
| Cost | Infrastructure costs are a limiting factor for many research projects, and must be managed diligently. |
| Flexibility | Flexibility regarding current and future computing equipment is important for all researchers. |
| Response/Uptime | Requirements related to response and uptime varied among staff and researchers. |
| Communications & Responsiveness | Disconnect between researchers and IT support staff was identified as a concern, though possible to mitigate. |
| Technical Expertise | The ability to find qualified staff to work in remote locations was identified as a concern. |
| Intermittent System Admin Tasks | Inconsistent and unpredictable needs of system administrators. |

Figure 7: Summary of Stakeholder Assessments

# 11.0 RECOMMENDATIONS

The recommendations have been organized to answer the two questions posed earlier. Question 1 pertains to data centre owners and asks, 'How can universities and other organizations create and maintain carbon neutral computing facilities that are cost-competitive?' Question 2 addresses the relocation issue separately, simply stated, 'Should an organization or user move its data centre to a low-carbon region, and can that move be financed through carbon offsets?' This second question assumes that the data centre already exists, and the scope of the question covers relocation expenses and costs to become carbon neutral. Operating costs are excluded because it is assumed that the data centre owner has similar expenses in the existing and proposed locations.

**Question 1: How can data centres be created to support low-carbon computing?**

Given that the majority of data centre GHG emissions are a direct result of their electricity consumption, and electricity emissions vary by region, it becomes apparent that the driver for creating low-carbon computing is locating data centres in regions that are supplied by a mix of renewable energy sources. Table 6 makes this point succinctly.

| CATEGORY | EMISSION INTENSITY RANGE (KG CO2E/KWH) | REPRESENTATIVE PROVINCE AND EMISSION INTENSITY | ANNUAL GHG EMISSIONS FROM 2 MW DATA CENTRE |
|---|---|---|---|
| Low | 0 to 0.1 | B.C. (0.0172) | 301 |
| Medium | 0.1 to 0.5 | Ontario (0.2207) | 3867 |
| High | 0.5 and above | Alberta (0.8166) | 14,307 |

Figure 8: Regional GHG Emissions Comparison

The scenarios in this report have been presented in order to best answer the question of how to create low carbon data centres. Scenarios 4, 4a and 4b demonstrate an approach that involves locating the data centre directly next to a source of renewable energy, however these scenarios are more costly (highest NPV) and also create limitations on where a data centre can be built. Renewable energy sources are often located in remote or rural areas, not near cities and telecommunications equipment. A disadvantage of Scenario 4 is that a single renewable energy project and data centre may not be sufficient to meet the needs of a research institution. Renewable energy can be intermittent, meaning that it ebbs and flows based on the wind, sun, or availability of other resources. One approach to mitigate this issue, outlined in scenario 4a, is to build multiple data centres next to a diverse mix of renewable energy sources, however this means a doubling, or more, of capital and operating costs. Replicated data and servers would be extremely costly and an inefficient use of resources for systems that do not require replication; servers would sit idle and unused while not in use. Another way to mitigate the intermittency is through the use of energy storage, however this also adds additional capital expenses and has not been considered here. Scenario 4b involves connecting the data centre and renewable energy source to the regional electrical grid, which would allow the data centre and energy source to deal with fluctuations in demand or supply. However for small scale projects the cost of transmissions lines is likely prohibitive. Scenario 4 therefore represents an overly optimistic situation, since neither energy storage nor multiple locations are included.

Scenario 3 demonstrates a more flexible approach for creating a carbon-neutral data centre by proposing that it be built in or near a city, connected to a low-carbon regional electrical grid that is supplied by renewable energy. Any emissions produced as a result of electricity consumption can then be offset through the purchase of renewable energy credits. This scenario also avoids the costly installation of dedicated renewable energy projects or data and electrical transmission lines. The other advantage of locating a data centre in or near a city are the available options for re-using the waste heat. Using waste heat to displace natural gas produces a net positive impact on GHG emissions, and this has been factored into the scenarios. Scenarios 1 and 2 are applicable to the case study at UBC and are less informative for the broader audience, particularly non-university environments. Excluding scenario 1 and 2, Scenario 3 has the best NPV, as well as the lowest operating and embodied GHG emissions.

This report recommends that in cases where a data centre has not yet been built, the decision should be made to locate the data centre in regions with low-carbon electric grids, and purchase renewable energy credits (green electricity premiums) to offset the remaining emissions. Alternately, direct investment in renewable energy sources, if the scale is large enough, may also be financially feasible and offers better assurances that incremental investments in renewable energy are occurring.[20] For the given size of this case study however, indirect investment in renewable energy through RECs proves more advantageous. Another factor in the importance to relocate to low carbon regions is the potential that forthcoming regulations concerning carbon offsets could make operating in high carbon areas expensive for high-energy consumers such as data centres who wish to simply purchase offsets to remain carbon neutral. For all these reasons, locating centres in low-carbon zones does not only make good environmental sense, it is also an important business cost cutting strategy for those operations wanting or needing to be carbon neutral.

### Question 2: Should an organization move its servers (co-located or rented) to a low-carbon region, and can the relocation expenses[21] be financed through carbon offsets?

There is a tremendous amount of variability when attempting to pose a recommendation for this question. Each relocation project is unique given the size of a data centre, the distance over which servers and other equipment must be moved, and the amount of downtime that can be tolerated by the systems and users. Moving a data centre while maintaining service levels will prove to be significantly more expensive than moving a data centre while it is offline. As such, this report will offer some brief guidelines and general rules, rather than a definitive recommendation.

[20] Gillenwater, M. (2008). Redefining RECs - Part 1: Untangling attributes and offsets. *Energy Policy,36* (6).

[21] Relocation expenses include all costs related to packing and shipping servers, reinstalling networks, and any costs from supporting temporary locations and maintaining up-time.

The decision regarding whether or not to relocate to a low-carbon region in order to achieve carbon neutrality is based on a number of factors, most notably the data centre's current GHG emissions and the cost of the relocation (not including capital costs). It is important to note the following:

a. If the servers do not move to another region, it is assumed that the operations will become carbon neutral through the purchase of carbon offsets for a period of 20 years. While a data centre may exist for upwards of 30 years, energy sources change over time therefore making it difficult to predict what the GHG emissions factors will be in the future. It is also difficult to predict with any certainty the cost of future carbon offsets, though the expectation is that carbon offset prices will increase over time as abatement costs rise.

b. If the servers do move, it can quantify the annual reductions in GHG emissions that will result from the move and may be able to sell the carbon credits on the appropriate carbon market.

To provide an example, a university in Alberta that has outgrown its current space and rather than build a new data centre in locally decides to move its servers (approx 2 MW) to a location in British Columbia may generate approximately 15,000 tonnes of CO2e savings per year, for a 10-year cumulative total of 150,000 carbon credits. If the data centre does sell the resulting GHG emission reductions it will receive the monetary value of 150,000 carbon credits (@ $10/credit), either as a lump sum in year one (less adjustments for lump sum payment), or annually for 10 years. Because the GHG reductions have been 'sold' or allocated elsewhere, the data centre cannot also claim the reductions, meaning that it must continue to record its annual emissions equivalent to that of prior years, for as long as it is receiving payments for the carbon credits (10 years).

Using the above example from Alberta, the data centre must continue to report its emissions as 15,000 tCO2e annually for 10 years, despite having real emissions of 300 tCO2e given its new location in BC. Selling the carbon credits while also claiming them would constitute 'double-counting', meaning that both the data centre and the organization that it sold the carbon credits to counted the GHG reductions. GHG reductions can only be counted one time, and then be fully retired. Once the 10-year period has expired, only than can the data centre begin to claim the emissions figures for its location, and claim the reductions.

If the organization wants to claim carbon neutrality in the first 10 years, it must purchase carbon offsets to cover the 15,000 tCO2e annually. During the first 10 years, the data centre is therefore recording a loss, since it is selling carbon credits at a wholesale rate ($10) and purchasing carbon offsets at a retailer rate ($25). However after 10 years, savings begin to accrue as the data centre avoids the full cost of carbon offsets, which it would otherwise still be paying if it had not relocated to the low-carbon region.

It is important to note that capital costs of building a new facility have been left out of the decision making process since the assumption is that a new data centre is being built regardless. Clearly differences in construction and operating costs between the two regions will also need to be factored into any final decision. Figure 9 below demonstrates the two options, calculated for a period of 20 years. Along the X-axis is the regional GHG emissions factor that is applied to electricity consumption at the data centre, and the Y-axis is cost.

**No Relocation**

Net present value of the 20-year purchase of carbon offsets

**Relocation**

Net present value of the relocation expenses + 10-year carbon offset purchases – 10-year carbon credit sales

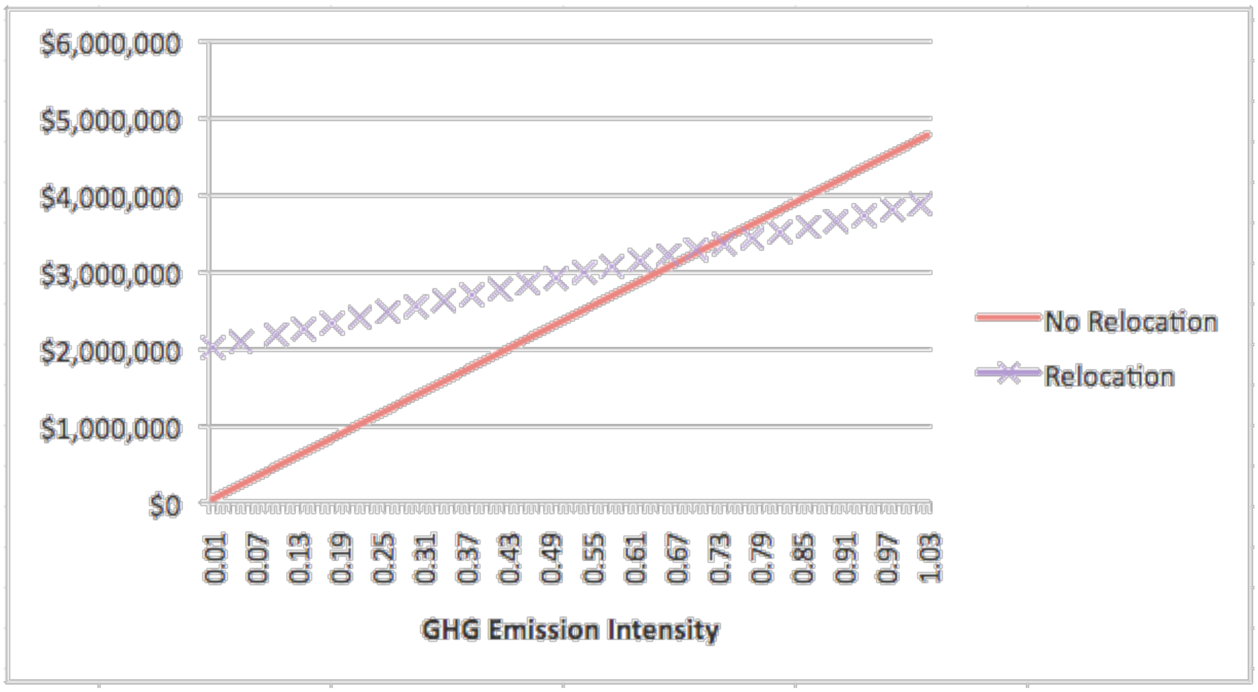


Figure 9: Sample Break Even. Details found in Appendix G

## Equation

To determine whether it makes financial sense to move regions when building a new data centre the following equation can be used:

X = NPV Carbon Offsets (20yr) – (Relocation costs + (NPV Carbon Offsets (10 yr) – NPV Carbon Credits (10yr))

Where X > 0, relocate data centre

Where X < 0, purchase carbon offsets, do not move

Given the above, it is financially advantageous to move a data centre from a high carbon area to a low-carbon area, provided that the resulting carbon credit sales, minus the relocation costs, are less than the organization would be paying in carbon offsets if it stayed in its current location. Figure 4 displays a graph to visually articulate this point using a hypothetical 2 MW data centre and relocation expenses of $2,000,000. Reading the graph left to right, the point at which the two lines cross (NPV of the carbon offset, Relocation expenses + 10 yr offsets – 10 yr credits) is the point at which it becomes advantageous for a data centre to relocate, given its regional emissions factor (X axis). A data centre with an emissions factor less than the breakeven point (0.70 tCO2e) is better off paying for carbon offsets and not relocating, while a data centre with an emissions factor greater than the breakeven (0.61 tCO2e) is better off relocating. More generally, it only makes sense for a data centre to relocate in order to become carbon neutral if it currently is in a jurisdiction with a GHG emissions factor of 0.70 tonnes CO2e/Kwh or higher. If the data centre was located in a jurisdiction with a lower emissions factor, the business case for moving might be more difficult to prove. There are however other considerations such as reputation, profile, or retention of customers, that have not been factored in at this stage.

This scenario represents a simplified version that has not factored in site-specific information or escalating carbon pricing. Decreasing the discount rate or increasing the value of carbon pricing into the future shift the breakeven point lower, making it advantageous to relocate given a lower emissions factor (i.e. less than 0.70 tCO2e). When applying this recommendation to a specific project, it will be important to conduct a sensitivity analysis, taking into account any presumed regulatory changes to carbon pricing, as well as the organizations identified discount rate. An alternate scenario also exists, whereby the data centre relocates and does not collect the carbon credits, choosing instead to claim carbon neutrality in year 1 after the move, rather than waiting until year 10. Essentially this suggests that a data centre should relocate to a zero-carbon area when the cost to stay and purchase carbon offsets exceeds the relocation expenses, which for the above example is when the emissions factor is above 0.42 tCO2e ($2,000,000 relocation expenses).

Overall the preferred decision is to pay the carbon offsets rather than relocate only for those data centres who already are situated in low or low-medium areas. High areas can generally finance a data centre move, however it is impacted by the relocation costs and GHG emissions factor of the original and new regions. In all cases it is assumed that the ultimate goal is to become carbon neutral, regardless of regulations dictating carbon pricing or other mechanisms.

# 12.0 APPENDIX

## 12.1 APPENDIX A: ENERGY METER READINGS: UBC SITES

| SITE | KW |
|---|---|
| IRC B6 | 0.35 |
| FSC 1806 | 0.53 |
| MacLeod 121A | 0.74 |
| EOS 106A | 0.80 |
| EOS 203A | 0.80 |
| ICICS 306A | 1.06 |
| SCARFE 1012B | 1.27 |
| SCARFE 1008F | 1.77 |
| Buchanan | 1.79 |
| ICICS X320 | 2.04 |
| SCARFE 1312A | 2.30 |
| Woodward 001 | 2.55 |
| ICICS X515 | 2.83 |
| ICICS X450 | 2.96 |
| AERL 409 | 3.54 |
| CEME 1057 | 3.54 |
| FSC 1502 | 4.69 |
| CEME 201D | 4.90 |
| FSC 2311 | 5.22 |
| Strangway 262 | 5.31 |
| ICICS 164 | 5.72 |
| Hennings 110A | 6.13 |
| AERL 309 | 6.45 |
| ICICS X420 | 6.66 |
| ICICS X120 | 7.55 |
| Koerner T183 | 7.60 |
| Koerner G323 | 8.69 |
| Kaiser 3035 | 8.88 |
| MacLeod 342A | 9.10 |
| LMRC 126C | 9.37 |
| LPC 33 | 10.36 |
| ICICS520 | 10.60 |
| LPC 233 | 11.45 |
| EOS 235 | 11.76 |
| LSC B2514 | 11.90 |
| ICICS X720 | 12.31 |
| EOS 223 | 12.51 |
| Hennings 317B | 13.97 |
| LSC B2516 | 22.66 |
| ICICS X220 | 23.49 |
| Henry Angus 59 | 29.07 |
| Klink 102 | 36.64 |
| Hennings 102B | 43.45 |
| ICICS 155 | 56.82 |
| Chemistry D115 | 61.78 |
| Klink 100G ** | 192.40 |
| **Total Power Usage** | **686** |

# 12.2 APPENDIX B: IMPORTANT CONCEPTS

### How energy consumption relates to the environment

Energy production for use in homes, businesses, and other commercial enterprises is produced using a number of methods, all with varying degrees of negative environmental impact. In North America and elsewhere, energy production is most often a mix of coal-fired plants, nuclear plants, natural gas (thermal) plants, and hydroelectric dams. On a much smaller but growing scale, renewable energy sources such as wind, geothermal, and solar also contribute to the energy mix. The way in which the environmental impact of energy production and consumption is measured is by the amount of greenhouse gas (GHG) emissions (CO2 equivalents) produced during the production phase. GHG emissions refer to a number of gases known to have detrimental effects on the Earth's atmospheric temperature by trapping excess heat (solar radiation). The production of these GHG emissions by human activities is known as anthropogenic sources, and is a major contributor to climate change (IPCC, 2007). Reducing the amount of GHG emissions released into the atmosphere can be tackled in one of two ways; by reducing the absolute consumption of GHG-intensive energy sources (i.e coal, natural gas), and by switching to low GHG energy sources (i.e. hydro, wind). This report focuses on the effect of switching to low GHG-emitting energy sources.

### Carbon Neutrality

An organization may be required by regulations to measure and track its total GHG emissions, or do so voluntarily. In either case, the ultimate aim is to eventually reduce GHG emissions down to zero. Depending on the nature of the organization or process, this may be unfeasible, in which case an organization will look to 'offset' its GHG emissions. An organization can offset its emissions by enabling a reduction in emissions elsewhere, either directly through actions, or indirectly through financing. This financial mechanism is known as carbon offsets, whereby one organization, in lieu of reducing its own emissions, invests in another firm or project; enabling a reduction in GHG emissions that would have otherwise not happened. When an organization has offset all of its emissions, it is said to have achieved carbon neutrality.

### Energy production across Canada

The GHG emissions from electricity generation vary significantly by region within Canada; therefore the strategy that a data centre must employ to become carbon neutral similarly varies across the country. British Columbia, with its low GHG emissions from electricity generation (22 tonnes CO2e / GWh), is inherently very green, and can effectively become carbon neutral through the re-use of waste heat, displacing other forms of heating (i.e. natural gas). However other locations such as Alberta, with substantially higher GHG emissions from electricity production (810 tonnes CO2e/GWh) will need to employ other solutions in order to demonstrate green infrastructure projects. For example, a typical 2 MW data centre will produce 385 tonnes of CO2e per year in the province of British Columbia, and 14,200 tonnes of CO2e per year in Alberta, equivalent to 37 times more CO2e per year. This importance difference plays a critical role in decision making for data centre locations and relocations.

### Rebound Effect

A very common theme emerging at the centre of technology and energy is the idea of energy efficiency. By creating technology and solutions that reduce their energy consumption while still providing the same level of service or unit of output, the expected outcome is that the absolute consumption of energy will be reduced. However in practice this often is not the case. Reducing the energy required to produce a product, offer a service, or run a technology solution often results in more of the product, service, or energy being consumed over time. Known as the rebound effect, it is similar to the Jevon's Paradox, an economic principle that states that as efficiencies in resource use are achieved, the result is an increase in absolute resource use, not a decrease. To illustrate a technical example, servers and more specifically CPUs and memory are becoming more energy efficient over time, yet at the same time more processing power is incorporated into each server, so gains made in energy efficiency are offset by more powerful and faster processing. It is for this reason that energy efficiency, particularly in the information technology sector, is not sufficient to meet long term environmental and sustainable objectives. Additional policies and strategies are needed in addition to energy efficiency.

## 12.3 APPENDIX C: TOTAL COST OF OWNERSHIP

| ENERGY AND POWER USE/COSTS | UNITS | SERVERS | DISK STORAGE | TAPE STORAGE | NETWORKING | TOTALS | NOTES |
|---|---|---|---|---|---|---|---|
| % of racks | | 80% | 8% | 2% | 10% | 100% | 1 |
| # of racks | | 160 | 16 | 4 | 20 | 200 | 2 |
| # of U per rack | | 42 | 42 | 42 | 42 | 42 | 3 |
| % filled | % | 76% | 76% | 76% | 76% | 76% | 4 |
| # of U filled | | 5120 | 511 | 128 | 638 | 6397 | 5 |
| | | | | | | | |
| Power use/filled U | W | 385 | 200 | 50 | 150 | 340 | 6 |
| Total power use/rack | kW/rack | 12.3 | 6.4 | 1.6 | 4.8 | 10.9 | 7 |
| Total Direct IT power use | kW | 1971 | 102 | 6 | 96 | 2175 | 8 |
| ***TOTAL ELECTRICITY USE*** | | | | | | | |
| IT (UPS) load | kW | 1971 | 102 | 6 | 96 | 2175 | 8 |
| Cooling | kW | 1281 | 66 | 4 | 62 | 1414 | 9 |
| Auxiliaries | kW | 690 | 36 | 2 | 34 | 761 | 10 |
| Total power use | kW | 3942 | 204 | 13 | 192 | 4351 | 11 |
| ***ELECTRIC POWER DENSITY*** | | | | | | | |
| IT load | W/sf elect. Active | 256 | 13 | 1 | 12 | 283 | 12 |
| Cooling | W/sf elect. Active | 166 | 9 | 1 | 8 | 184 | 12 |
| Auxiliaries | W/sf elect. Active | 90 | 5 | 0 | 4 | 99 | 12 |
| Total power use | W/sf elect. Active | 512 | 27 | 2 | 25 | 565 | 12 |
| ***TOTAL ELECTRICITY CONSUMPTION*** | | | | | | | |
| IT load | M kWh/year | 16.4 | 0.9 | 0.1 | 0.8 | 18.1 | 13 |
| Cooling | M kWh/year | 10.7 | 0.6 | 0.0 | 0.5 | 11.8 | 13 |
| Auxiliaries | M kWh/year | 5.7 | 0.3 | 0.0 | 0.3 | 6.3 | 13 |
| Total electricity use | M kWh/year | 32.8 | 1.7 | 0.1 | 1.6 | 36.2 | 13 |
| ***TOTAL ENERGY COST*** | | | | | | | |
| IT load | M $/year | 0.71 | 0.04 | 0.00 | 0.03 | 0.78 | 14 |
| Cooling | M $/year | 0.46 | 0.02 | 0.00 | 0.02 | 0.51 | 14 |
| Auxiliaries | M $/year | 0.25 | 0.01 | 0.00 | 0.01 | 0.27 | 14 |
| Total electricity cost | M $/year | 1.41 | 0.07 | 0.00 | 0.07 | 1.56 | 14 |

| Energy and power use/costs | Units | Servers | Disk storage | Tape storage | Networking | Totals | Notes |
|---|---|---|---|---|---|---|---|
| **CAPITAL COSTS (Cap Ex)** | | | | | | | |
| ***IT CAPITAL COSTS*** | | | | | | | |
| Watts per thousand $ of IT costs | watts/thousand $ | 86 | 30 | 6 | 100 | | 15 |
| Cost per filled U | k $/U | 4.5 | 6.7 | 8.3 | 1.5 | | 16 |
| Cost per filled rack | k $/rack | 189 | 280 | 350 | 63 | | 17 |
| Total IT costs | M $ | 23.0 | 3.4 | 1.1 | 1.0 | 0 | 18 |
| ***OTHER CAPITAL COSTS*** | | | | | | | |
| Rack costs | k $/rack | 3 | 3 | 3 | 3 | | 19 |
| External hardwired connections | k $/rack | 5 | 5 | 5 | 5 | | 20 |
| Internal routers and switches | k $/rack | 5 | 5 | 5 | 5 | | 21 |
| Rack management hardware | k $/rack | 3 | 3 | 3 | 3 | | 22 |
| | | | | | | | |
| Rack costs total | M $ | 0.48 | 0.05 | 0.01 | 0.06 | 0.6 | 23 |
| External hardwired connections total | M $ | 0.80 | 0.08 | 0.02 | 0.10 | 1.0 | 23 |
| Internal routers and switches total | M $ | 0.80 | 0.08 | 0.02 | 0.10 | 1.0 | 23 |
| Rack management hardware total | M $ | 0.48 | 0.05 | 0.01 | 0.06 | 0.6 | 23 |
| | | | | | | | |
| Cabling costs (total) | | | | | | 1.3 | 24 |
| | | | | | | | |
| Point of Presence (POP) | M $ | | | | | 3.5 | 25 |
| | | | | | | | |
| kW related infrastructure costs | M $ | 22.7 | 1.2 | 0.1 | 1.1 | 25.0 | 26 |
| Other facility costs (elect. active) | M $ | | | | | 4.0 | 27 |
| Interest during construction | M $ | | | | | 0.0 | 28 |
| Land costs | M $ | | | | | 0.00 | 29 |
| Architectural and engineering fees | M $ | | | | | 1.5 | 30 |
| Inert gas fire suppression | M $ | | | | | 0.4 | 31 |
| *Total installed capital costs* | *M $* | | | | | *38.9* | |
| | *$/sf elect. active* | | | | | *5046* | |
| Capital costs with 3 yr life. | M $ | | | | | 1.6 | 32 |

| ENERGY AND POWER USE/COSTS | UNITS | SERVERS | DISK STORAGE | TAPE STORAGE | NETWORKING | TOTALS | NOTES |
|---|---|---|---|---|---|---|---|
| Capital costs with 5 year life | M $ | | | | | 1.0 | 32a |
| Capital costs with 15 year life | M $ | | | | | 36.3 | 33 |
| | | | | | | | |
| *Annualized capital costs* | *M $/year* | | | | | *4.248186* | 34 |
| | | | Energy and power use/cosotes | | | | |
| Annual operating expenses (Op Ex) | | | | | | | |
| | | | | | | | |
| *Total electricity costs* | *M $/year* | *1.4* | *0.1* | *0.00* | *0.1* | *1.6* | 35 |
| *Network fees* | *M $/year* | | | | | *0* | 36 |
| *Other operating expenses* | | | | | | | 37 |
| IT site management staff | M $/year | | | | | 0.26 | 38 |
| Facilities site management staff | M $/year | | | | | 0.13 | 39 |
| Maintenance | M $/year | | | | | 0.10 | 40 |
| Janitorial and landscaping | M $/year | | | | | 0.00 | 41 |
| Maintenance | M $/year | | | | | 0.20 | 42 |
| Property taxes | M $/year | | | | | 0.36 | 43 |
| Total other operating expenses | M $/year | | | | | 1.06 | |
| | | | | | | | |
| *Total operating expenses* | *M $/year* | | | | | *2.6* | 44 |
| | | | | | | | |
| Total Annualized costs | | | | | | | |
| Total | M $/year | | | | | 6.9 | 45 |
| Per unit of electrically active floor space | $/sf/year | | | | | 891 | 46 |
| Per server | $/server/year | | | | | 1340 | 47 |

| ASSUMPTIONS (NOTE: ALL COSTS ARE 2007 DOLLARS) | |
|---|---|
| 1) Fraction of racks allocated to different categories based on Uptime institute consulting experience and judgment for high performance computing in financial applications. | |
| 2) Number of racks calculated based on 20ksf electrically active floor area, 100 square feet per rack, and percentage breakdown from previous row. | 43 SQFT per rack |
| 3) Racks are standard (6.5 feet high with 42 Us per rack). | |
| 4) % of rack filled based on Uptime consulting experience. | |
| 5) The total number of Us filled is the product of the number of racks times total Us per rack times the % filled. | |
| 6) Energy use per U taken from selective review of market/technology data. Server power and costs per watt assumes IBM X-3550 1U system. | |
| 7) Energy use per rack is the product of the total number of Us filled times watts per installed U. | |
| 8) Total direct IT energy use is the product of watts per rack times the number of racks of a given type. | |
| 9) Cooling electricity use (including chillers, fans, pumps, CRAC units) is estimated as 0.65 times the IT load . | |
| 10) Auxiliaries electricity use (including UPS/PDU losses, lights, and other losses) is estimated as 0.35 times IT load. | 9 + 10 --> PUE = 2 |
| 11) Total electricity use is the sum of IT, cooling, and auxiliaries. Cooling and auxiliaries together are equal to the IT load (Power overhead multiplier = 2.0). | |
| 12) Electricity intensity is calculated by dividing the power associated with a particular component (eg IT load) by the total electrically active area of the facility. | |
| 13) Total electricity consumption is calculated using the total power, a power load factor of 95%, and 8766 hours/year (average over leap and non-leap years). | |
| 14) Total energy cost calculated by multiplying electricity consumption by the average U.S. industrial electricity price in 2007 (6.8 cents/kWh, 2007 dollars). | |
| 15) Watts per thousand 2007 dollars of IT costs taken from selective review of market and technology data. Server number calculated assuming IBM x3550 1U server as described in next note. | Hardware not included |
| 16) Cost per filled U taken from selective review of market and technology data. Server street cost calculated assuming IBM x3550 1U server with 8 GB RAM, two dual core 2.66 GHz Intel processors (19.2 GFLOPS max/server). | Hardware not included |
| 17) Cost per filled rack is the product of the cost per U and the total # of Us per rack (42). | Hardware not included |
| 18) Total IT costs are the product of the number of filled Us and the cost per filled U. | Hardware not included |
| 19) Rack costs are the costs of the rack structure alone. | |
| 20) External hardwired connections costs are Uptime estimates. | |
| 21) Internal routers and switch costs are Uptime estimates. | |
| 22) Rack management hardware costs are Uptime estimates. | |
| 23) Total costs for racks, hardwired connections, and internal routers and switches are the product of the cost per rack and the number of racks. | |
| 24) Cabling costs totals are Uptime estimates. | |
| 25) Point of presence costs are Uptime estimates for a dual POP OC96 installation. | POP not included |
| 26) kW related infrastructure costs (taken from Turner and Seader 2006) are based on Tier 3 architecture, $23,801 per kW cost. Assumes immediate full build out. Includes costs for non electrically active area. Construction costs escalated to 2007$ using Turner construction cost indices for 2005 and 2006 (http://www.turnerconstruction.com/corporate/content.asp?d=20) and 2007 forecast | Use $11.5K/sqft Tier 1-2 |

| | |
|---|---|
| (http://www.turnerconstruction.com/corporate/content.asp?d=5952). Electricity prices escalated to 2007$ using the GDP deflator 2005 to 2006 and 3% inflation for 2006 to 2007. | |
| 27) Other facility costs are based on $262 per square foot of electrically active area (taken from Turner and Seader 2006. Costs are in 2007 $, escalated as described in the previous footnote). | To cover construction of sub-basement ($400/sqft) |
| 28) Interest during construction estimated based on total infrastructure and other facility capital costs assuming a 7% real interest rate for one year. | Not included |
| 29) Land cost based on $100,000 per acre, 5 acres total. | Land not included |
| 30) Architectural and engineering fees are estimated as 5% of kW related infrastructure costs plus other facility costs (electrically active). Cost percentage is based on personal communication with Peter Rumsey of Rumsey Engineers, 9 July 2007. | |
| 31) Cost for inert gas fire suppression are Uptime estimates ($50/sf of electrically active floor area). | |
| 32) Capital costs with three year life include all IT equipment costs (which include internal routers and switches). | |
| 33) Capital costs with 15 year lifetime include all capital costs besides IT costs (these costs also include rack, cabling, and external hardwire connection costs). Minus 32a | |
| 32a) Batteries assumed to be $1M and replaced every 5 years | |
| 34) Capital costs are annualized with the capital recovery factor calculated using the appropriate lifetime (three or 15 years) and a 7% real discount rate. | UPS should be 5 years but left as 15 for now |
| 35) Total electricity costs include both IT and infrastructure energy costs (see notes 11, 12, 13, & 14). | |
| 36) Network fees are Uptime estimates. | |
| 37) Other operating expenses based on Uptime Institute estimates for a Midwest mid-size town location. Benefits are assumed to be equal to 30% of salary. | |
| 38) IT site management staff costs assume $100k/yr salary, 3 people per shift, 1 shift per day. | 0.5 FTE |
| 39) Facilities site management staff costs assume $100k/yr salary, 3 people per shift, 1 shift per day. | 0.5 FTE |
| 40) Maintenance costs assume non-union in-house facilities staff, $80k/yr salary, 4 people per shift, 1 shift per day. | 0.5 FTE |
| 41) Janitorial and landscaping costs assume $4/gross square foot of building area per year (based on Uptime estimates). | Not included |
| 42) Maintenance: $150K cooling, $20K generator, $30K SW (security & monitoring) | |
| 43) Annual property taxes estimated as 1% of the total installed capital cost of the building (not including IT costs). | Not included |
| 44) Total operating expenses include electricity costs, network fees, and other operating expenses. | |
| 45) Total annualized costs include capital and operating costs. | |
| 46) Costs per square foot per year are calculated by dividing total annualized costs by the total electrically active floor area. | |
| 47) Costs per server are calculated assuming that all servers are 1U Volume servers and by dividing total annualized costs by the number of Us occupied by servers. | |

## 12.4 APPENDIX D: STAKEHOLDER ASSESSMENT DETAILS

One-on-one stakeholder interviews were conduced with a staff and faculty at the University of British Columbia, and the details have been summarized into a number of recurring themes, outlined below. More detailed notes are available by request.

#### Physical Access

Physical access to the equipment is infrequently required in the majority of cases, and is only necessary to swap out or fix hardware components. Software installations, upgrades, and other configuration can be done remotely. However it was noted that during initial project development or testing, access to the equipment can be required on a project-specific basis, to allow for hardware testing and changes. During the more mature phases of a project, physical access is required on a less frequent basis, depending on the project.

#### Bandwidth

Bandwidth and effective throughput are critically important in a significant number of research projects, as data results (post-process data) must be sent to the researchers for further analysis or input into other process. To illustrate and example, Earth and Ocean Sciences conducts weather modeling on a daily basis, and this information, approximately 200 Gb, is sent every day to external organizations. Other projects involve large amounts of data that is used in visualization or modeling software, and these software technologies must continue to operate within adequate response times. Bandwidth is a critical and potentially limiting factor to moving HPC equipment to a remote location. Without sufficient bandwidth, researchers will not be able to utilize remote locations.

#### Cost

The ability to provide a solution that is cost-effective is critical for all stakeholders and is particularly important for researchers. Funds from granting organizations typically cover infrastructure costs but not operating costs, so the researchers' ability to cover operating costs is severely limited. Infrastructure costs must also be appropriate and justifiable, and have historically been $10,000 per rack on average. The University receives a percentage of total grants from funding agencies to cover 'indirect costs of research'. These funds are meant to cover costs of electricity and network infrastructure.

#### Flexibility

All researchers and support staff expressed a need for flexibility regarding their current and future computing equipment. Some had concerns that moving their equipment to a centralized location would eventually force them to purchase and/or use homogenous computing equipment that would not meet their needs. While there is no clear direction on how to meet this requirement, having an understanding of researchers' other needs and variability of them is critical for maintaining flexibility of options. Any eventual centralized space, be it on-campus or remotely, would need to cater to a multitude of equipment specifications and end-user requirements. As such, rack space and power/cooling would need to be flexible, and support staff would need a level of expertise to deal with varying technologies.

#### Response / Uptime

Researchers have varying requirements for uptime and responsiveness of their respective equipment. Some researchers require almost 24/7 uptime with allowance for short breaks, while others have very high tolerances for downtime. Earth and Ocean Sciences produces daily weather forecasts for external organizations, therefore it is less tolerant of outages than some others whose data is only used internally.

### Communication & Responsiveness

Some researchers noted that loss of communication between system administrators and the end-users would result from relocating the equipment to a remote location. The ability of some personnel to perform both research and system admin tasks would be eliminated, therefore information sharing and common understandings of issues could be compromised.

### Technical Expertise

The ability to find qualified staff to work in a remote location was identified by stakeholders as a potential constraint. Staff who currently perform system administration functions are highly qualified individuals, and the likelihood of finding similar staff in a rural location could be challenging.

### Intermittent System Administration Tasks

All researchers and support personal indicated that the system administration tasks are not performed on a daily or recurring basis, but rather as needed. There is an inconsistent and unpredictable need for system administrators. The question therefore becomes, will the aggregation of multiple HPC equipments mitigate this inherent fluctuation. Assuming enough equipment is centralized, the answer is yes.

# 12.5 APPENDIX E: FINANCIAL MODELS

## Scenerio 1: As Is + Governance: 20 Year Period 2010-2030

| Year | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | Horizon | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Capital Costs | | | | | | | | | | | | | 0 |
| LPC upgrade (18 racks) | 1,300,000 | | | | | | | | | | | | 1,300,000 |
| Klinck upgrade (24 racks) | | 1,800,000 | | | | | | | | | | | 1,800,000 |
| Other upgrades | | | 900,000 | | | | | | | | | | 900,000 |
| Engineering + 50% build | | | | 3,000,000 | | | | | | | | | 3,000,000 |
| PharmSci 50% build +core | | | | | 8,000,000 | | | | | | | | 8,000,000 |
| Additional Rack build out | | | | | | 6,000,000 | 6,000,000 | 6,000,000 | 6,000,000 | 3,500,000 | | | 27,500,000 |
| Waste Heat Infrastructure | | | | 150,000 | 150,000 | 150,000 | | | | | | | 450,000 |
| Total Capital Costs | 1,300,000 | 1,800,000 | 900,000 | 3,150,000 | 8,150,000 | 6,150,000 | 6,000,000 | 6,000,000 | 6,000,000 | 3,500,000 | 0 | 0 | 42,950,000 |
| Operating Costs | | | | | | | | | | | | | 0 |
| Electrical Load (KW) | 2300 | 2461 | 2633 | 2818 | 3015 | 3226 | 3452 | 3693 | 3952 | 4228 | 4524 | | |
| Loan Repayment | | | | | 738,517 | 1,312,938 | 1,910,833 | 2,535,775 | 3,192,161 | 3,596,605 | 3,596,605 | 25,676,014 | 42,559,449 |
| Electricity cost | 1,722,654 | 1,843,240 | 1,972,267 | 2,110,325 | 2,258,048 | 2,416,111 | 2,585,239 | 2,766,206 | 2,959,840 | 3,167,029 | 3,388,721 | 24,191,932 | 51,381,613 |
| Maintenance/Monitoring | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 1,427,792 | 3,127,792 |
| Other O&M costs | | | | | | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 2,855,583 | |
| Renewable Energy Credits | 604,440 | 646,751 | 692,023 | 740,465 | 792,298 | 847,758 | 907,101 | 970,599 | 1,038,540 | 1,111,238 | 1,189,025 | 5,161,838 | |
| 1 FTE | | | | | | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 | 713,897 | 1,313,897 |
| Total Operating Costs | 2,427,094 | 2,589,991 | 2,764,290 | 2,950,790 | 3,888,862 | 5,276,808 | 6,103,174 | 6,972,579 | 7,890,542 | 8,574,873 | 8,874,352 | 60,027,057 | 118,340,411 |
| Total Costs | 3,727,094 | 4,389,991 | 3,664,290 | 6,100,790 | 3,888,862 | 5,276,808 | 6,103,174 | 6,972,579 | 7,890,542 | 8,574,873 | 8,874,352 | 60,027,057 | 125,490,411 |
| | | | | | | | | | | | | | 0 |
| Benefits | | | | | | | | | | | | | 0 |
| IT Load (KW) | | | | | | 1000 | 1300 | 1600 | 1900 | 2,000 | 2,000 | 2,000 | |
| Natural Gas Savings* | | | | | | 157,770 | 220,878 | 252,400 | 299,763 | 315,540 | 315,540 | 3,143,089 | 4,704,980 |
| Carbon Tax Savings | | | | | | 54,450 | 76,230 | 43,560 | 51,735 | 54,450 | 54,450 | 542,376 | 877,251 |
| Carbon Offset Savings | | | | | | 45,375 | 63,525 | 36,300 | 43,113 | 45,375 | 45,375 | 451,981 | 731,043 |
| Electrical Savings (PUE) *** | | | | | | 178,923 | 232,600 | 286,277 | 339,954 | 357,846 | 357,846 | 3,564,498 | 5,317,944 |
| Avoided construction costs | | | | | | 600,000 | 600,000 | 600,000 | 600,000 | 600,000 | | | 3,000,000 |
| Total Benefits | 0 | 0 | 0 | 0 | 0 | 0 | 1,193,233 | 1,218,537 | 1,334,564 | 1,373,211 | 773,211 | 7,701,944 | 13,594,700 |
| Net Cost (Benefit) | -3,727,094 | -4,389,991 | -3,664,290 | -6,100,790 | -3,888,862 | -5,276,808 | -4,909,941 | -5,754,043 | -6,555,978 | -7,201,662 | -8,101,141 | -52,325,112 | -111,895,711 |
| Net Present Value | ($73,186,448) | | | | | | | | | | | | |

## Scenerio 2: PHARMSCI Build 2MW: 20 Year Period 2010-2030

| Year | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | Horizon | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Capital Costs | | | | | | | | | | | | | |
| Building KW Infrastructure | 25,000,000 | | | | | | | | | | | | |
| Racks, routers, switches | 3,200,000 | | | | | | | | | | | | |
| Additional floor area | 4,000,000 | | | | | | | | | | | | |
| Architecture fees | 1,500,000 | | | | | | | | | | | | 1,500,000 |
| Fire Suppression | 400,000 | | | | | | | | | | | | 400,000 |
| Contingency | 5,835,000 | | | | | | | | | | | | 5,835,000 |
| | | | | | | | | | | | | | |
| Total Capital Costs | 39,935,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 39,935,000 |
| Electrical load (KW) | 2100 | 2247 | 2404 | 2573 | 2753 | 2945 | 3152 | 3372 | 3608 | 3861 | 4131 | | |
| Operating Costs | | | | | | | | | | | | | 0 |
| Data centre relocation costs | 500,000 | | | | | | | | | | | | |
| Loan repayment | 3,364,525 | 3,364,525 | 3,364,525 | 3,364,525 | 3,364,525 | 3,364,525 | 3,364,525 | 3,364,525 | 3,364,525 | 3,364,525 | 3,364,525 | 14,606,194 | 51,615,964 |
| Electricity cost | 1,572,858 | 1,682,958 | 1,800,765 | 1,926,819 | 2,061,696 | 2,206,015 | 2,360,436 | 2,525,666 | 2,702,463 | 2,891,635 | 3,094,050 | 13,431,999 | 38,257,359 |
| Less energy efficiency ** | | | -180,076 | -192,681 | -206,169 | -220,600 | -236,043 | -252,566 | -270,245 | -289,163 | -309,404 | -1,343,194 | |
| Maintenance/Monitoring | 0 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 868,248 | 2,868,248 |
| 2 FTEs | | | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 868,248 | 2,668,248 |
| Other O&M costs | | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 1,736,495 | |
| Renewable Energy Credits | 551,880 | 590,512 | 631,847 | 676,077 | 723,402 | 774,040 | 828,223 | 886,199 | 948,233 | 1,014,609 | 1,085,631 | 4,712,983 | |
| Shadow Price of Carbon | 119,935 | | | | | | | | | | | | |
| | | | | | | | | | | | | | 0 |
| Total Operating Costs | 6,109,198 | 6,237,994 | 6,417,062 | 6,574,739 | 6,743,454 | 6,923,979 | 7,117,141 | 7,323,824 | 7,544,975 | 7,781,606 | 8,034,802 | 34,880,971 | 111,689,745 |
| | | | | | | | | | | | | | 0 |
| Total Costs | 6,109,198 | 6,237,994 | 6,417,062 | 6,574,739 | 6,743,454 | 6,923,979 | 7,117,141 | 7,323,824 | 7,544,975 | 7,781,606 | 8,034,802 | 34,880,971 | 111,689,745 |
| Benefits | | | | | | | | | | | | | 0 |
| IT Load (KW) | | | 1000 | 1300 | 1600 | 1900 | 2000 | 2000 | 2000 | 2000 | 2000 | | |
| Natural Gas Savings* | | | 157,770 | 220,878 | 252,400 | 299,763 | 315,540 | 315,540 | 315,540 | 315,540 | 315,540 | 1,369,834 | 3,878,345 |
| Carbon Tax Savings | | | 54,450 | 76,230 | 43,560 | 51,735 | 54,450 | 54,450 | 54,450 | 54,450 | 54,450 | 236,381 | 734,606 |
| Carbon Offset Savings | | | 45,375 | 63,525 | 36,300 | 43,113 | 45,375 | 45,375 | 45,375 | 45,375 | 45,375 | 196,985 | 612,172 |
| | | | | | | | | | | | | | 0 |
| Total Benefits | 0 | 0 | 257,595 | 360,633 | 332,260 | 394,611 | 415,365 | 415,365 | 415,365 | 415,365 | 415,365 | 1,803,200 | 5,225,124 |
| Net Cost (Benefit) | -6,109,198 | -6,237,994 | -6,159,467 | -6,214,106 | -6,411,194 | -6,529,369 | -6,701,776 | -6,908,459 | -7,129,610 | -7,366,241 | -7,619,437 | -33,077,771 | -106,464,621 |
| Net Present Value | ($73,737,977.10) | | | | | | | | | | | | |

## Scenerio 3: Offsite City: 20 Year Period 2010-2030

| Year | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | Horizon | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Data Centre | | | | | | | | | | | | | |
| Building KW Infrastructure* | 25,000,000 | | | | | | | | | | | | |
| Racks, routers, switches | 3,200,000 | | | | | | | | | | | | |
| Cabling | 1,300,000 | | | | | | | | | | | | |
| Point of Presence | 3,500,000 | | | | | | | | | | | | |
| Additional floor area | 4,000,000 | | | | | | | | | | | | |
| Architecture fees | 1,500,000 | | | | | | | | | | | | |
| Fire Suppression | 400,000 | | | | | | | | | | | | |
| Contingency | 5,835,000 | | | | | | | | | | | | |
| *SubTotal* | 44,735,000 | | | | | | | | | | | | |
| *Real Estate *** | 2,000,000 | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| Total Capital Expenses | 44,735,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | | | | | | | | | | | |
| Electrical load | 2100 | 2247 | 2404 | 2573 | 2753 | 2945 | 3152 | 3372 | 3608 | 3861 | 4131 | | |
| | | | | | | | | | | | | | |
| Operating Expenses | | | | | | | | | | | | | |
| Loan Repayment | 3,768,925 | 3,768,925 | 3,768,925 | 3,768,925 | 3,768,925 | 3,768,925 | 3,768,925 | 3,768,925 | 3,768,925 | 3,768,925 | 3,768,925 | 16,361,789 | 57,819,961 |
| Electricity | 0 | 0 | 1,800,765 | 1,926,819 | 2,061,696 | 2,206,015 | 2,360,436 | 2,525,666 | 2,702,463 | 2,891,635 | 3,094,050 | 13,431,999 | 35,001,543 |
| Maintenance/Monitoring | 0 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 200,000 | 868,248 | 2,868,248 |
| 3 FTE | 0 | 300,000 | 300,000 | 300,000 | 300,000 | 300,000 | 300,000 | 300,000 | 300,000 | 300,000 | 300,000 | 1,302,372 | 4,302,372 |
| Property Taxes | 36,000 | 36,000 | 36,000 | 36,000 | 36,000 | 36,000 | 36,000 | 36,000 | 36,000 | 36,000 | 36,000 | 156,285 | 552,285 |
| Green Energy Premium (RECs) | 0 | 0 | 631,847 | 676,077 | 723,402 | 774,040 | 828,223 | 886,199 | 948,233 | 1,014,609 | 1,085,631 | 4,712,983 | 12,281,244 |
| Other O&M costs | | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 1,736,495 | 5,736,495 |
| Shadow Price of Carbon | 183,845 | | | | | | | | | | | | 183,845 |
| Total Operating Expenses | 3,988,770 | 4,704,925 | 7,137,537 | 7,307,820 | 7,490,023 | 7,684,980 | 7,893,583 | 8,116,790 | 8,355,620 | 8,611,169 | 8,884,606 | 32,120,693 | 112,296,515 |
| Net Present Value | ($77,243,725) | | | | | | | | | | | | |

## Scenerio 4: Offsite City: 20 Year Period 2010-2030

| Year | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | Horizon | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Data Centre | | | | | | | | | | | | | |
| Building KW Infrastructure | 25,000,000 | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 25,000,000 |
| Racks, routers, switches | 3,200,000 | | | | | | | | | | | | |
| Cabling | 1,300,000 | | | | | | | | | | | | |
| Point of Presence | 3,500,000 | | | | | | | | | | | | |
| Additional floor area | 4,000,000 | | | | | | | | | | | | |
| Architecture fees | 1,500,000 | | | | | | | | | | | | |
| Fire Suppression | 400,000 | | | | | | | | | | | | |
| Contingency | 5,835,000 | | | | | | | | | | | | |
| *SubTotal* | 44,735,000 | | | | | | | | | | | | |
| Renewable Energy | | | | | | | | | | | | | |
| (4 MW) | 20,000,000 | | | | | | | | | | | | |
| infrastructure **** | 7,500,000 | | | | | | | | | | | | |
| Contingency, permitting, etc | 0 | | | | | | | | | | | | |
| *Sub Total* | 27,500,000 | | | | | | | | | | | | |
| Real Estate | 2,000,000 | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| Total Capital Costs | 72,235,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 25,000,000 |
| Operating Costs | | | | | | | | | | | | | |
| Loan repayment | 6,085,800 | 6,085,800 | 6,085,800 | 6,085,800 | 6,085,800 | 6,085,800 | 6,085,800 | 6,085,800 | 6,085,800 | 6,085,800 | 6,085,800 | 26,419,891 | 93,363,694 |
| Electricity cost | 0 | 0 | 400,170 | 428,182 | 458,155 | 490,225 | 524,541 | 561,259 | 600,547 | 642,586 | 687,567 | 2,984,889 | 7,778,121 |
| Maintenance/Monitoring *** | 0 | 300,000 | 300,000 | 300,000 | 300,000 | 300,000 | 300,000 | 300,000 | 300,000 | 300,000 | 300,000 | 1,302,372 | 4,302,372 |
| 4 FTEs | 0 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 1,736,495 | 5,736,495 |
| Shadow Price of Carbon | 798,294 | | | | | | | | | | | | |
| Travel | 25,000 | 25,000 | 25,000 | 25,000 | 25,000 | 25,000 | 25,000 | 25,000 | 25,000 | 25,000 | 25,000 | 108,532 | 383,532 |
| Property Taxes | 38,000 | 38,000 | 38,000 | 38,000 | 38,000 | 38,000 | 38,000 | 38,000 | 38,000 | 38,000 | 38,000 | 164,968 | 582,968 |
| Network fees | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 | 434,125 | 1,000,000 |
| Other O&M costs | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 1,736,495 | |
| Hydro electricity O&M | 154,158.48 | 164,949.57 | 176,496.04 | 188,850.77 | 202,070.32 | 216,215.24 | 231,350.31 | 247,544.83 | 264,872.97 | 283,414.08 | 303,253.06 | 1,316,494 | |
| Total Operating Costs | 7,601,253 | 7,513,750 | 7,925,466 | 7,965,833 | 8,009,025 | 8,055,241 | 8,104,692 | 8,157,604 | 8,214,221 | 8,274,800 | 8,339,620 | 36,204,252 | 124,365,757 |
| Net Cost (Benefit) | -7,601,253 | -7,513,750 | -7,925,466 | -7,965,833 | -8,009,025 | -8,055,241 | -8,104,692 | -8,157,604 | -8,214,221 | -8,274,800 | -8,339,620 | -35,922,854 | -124,084,358 |
| **Net Present Value** | ($86,849,793) | | | | | | | | | | | | |

## Scenerio 4B: Offsite Remote: 20 Year Period 2010-2030

| Year | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | Horizon | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Data Centre | | | | | | | | | | | | | |
| Building KW Infrastructure | 25,000,000 | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 25,000,000 |
| Racks, routers, switches | 3,200,000 | | | | | | | | | | | | |
| Cabling | 1,300,000 | | | | | | | | | | | | |
| Point of Presence | 3,500,000 | | | | | | | | | | | | |
| Additional floor area | 4,000,000 | | | | | | | | | | | | |
| Architecture fees | 1,500,000 | | | | | | | | | | | | |
| Fire Suppression | 400,000 | | | | | | | | | | | | |
| Contingency | 5,835,000 | | | | | | | | | | | | |
| *SubTotal* | 44,735,000 | | | | | | | | | | | | |
| Renewable Energy | | | | | | | | | | | | | |
| Hydro electricity infrastructure | 20,000,000 | | | | | | | | | | | | |
| ***** | 225,000,000 | | | | | | | | | | | | |
| Substation, transformers | 30,000,000 | | | | | | | | | | | | |
| Contingency, permitting, etc | 82,500,000 | | | | | | | | | | | | |
| *Sub Total* | 357,500,000 | | | | | | | | | | | | |
| Real Estate | 2,000,000 | | | | | | | | | | | | |
| Total Capital Costs | 402,235,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 25,000,000 |
| Operating Costs | | | | | | | | | | | | | |
| Loan Repayment | 33,888,307 | 33,888,307 | 33,888,307 | 33,888,307 | 33,888,307 | 33,888,307 | 33,888,307 | 33,888,307 | 33,888,307 | 33,888,307 | 33,888,307 | 147,117,112 | |
| Electricity cost | 0 | 0 | 400,170 | 428,182 | 458,155 | 490,225 | 524,541 | 561,259 | 600,547 | 642,586 | 687,567 | 2,984,889 | 7,778,121 |
| Maintenance/Monitoring *** | 0 | 300,000 | 300,000 | 300,000 | 300,000 | 300,000 | 300,000 | 300,000 | 300,000 | 300,000 | 300,000 | 1,302,372 | 4,302,372 |
| 4 FTEs | 0 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 1,736,495 | 5,736,495 |
| Shadow Price of Carbon | 1,868,828 | | | | | | | | | | | | |
| Travel | 25,000 | 25,000 | 25,000 | 25,000 | 25,000 | 25,000 | 25,000 | 25,000 | 25,000 | 25,000 | 25,000 | 108,532 | 383,532 |
| Property Taxes | 38,000 | 38,000 | 38,000 | 38,000 | 38,000 | 38,000 | 38,000 | 38,000 | 38,000 | 38,000 | 38,000 | 164,968 | 582,968 |
| Network fees | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 | 434,125 | 1,000,000 |
| Other O&M costs | | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 400,000 | 1,736,495 | |
| HydroElectricity O&M | 154,158 | 164,950 | 176,496 | 188,851 | 202,070 | 216,215 | 231,350 | 247,545 | 264,873 | 283,414 | 303,253 | 1,316,494 | |
| Total Operating Costs | 36,074,294 | 35,316,257 | 35,727,973 | 35,768,340 | 35,811,532 | 35,857,748 | 35,907,199 | 35,960,111 | 36,016,727 | 36,077,307 | 36,142,127 | 156,901,474 | 551,561,088 |
| Net Cost (Benefit) | -36,074,294 | -35,316,257 | -35,727,973 | -35,768,340 | -35,811,532 | -35,857,748 | -35,907,199 | -35,960,111 | -36,016,727 | -36,077,307 | -36,142,127 | -156,620,075 | -551,279,690 |
| Net Present Value | ($387,588,191) | | | | | | | | | | | | |

## Sensitivity of NDP Results to Discount Rate

| Discount Rate | 1: As-is | 2: Consolidation | 3: Offsite City | 4: Remote Site, Networked | 4a: Remote Site, Duplicated | 4b: Remote Site, On-grid |
|---|---|---|---|---|---|---|
| 3% | ($110,619,458) | ($102,008,359) | ($107,191,146) | ($118,858,734) | ($356,576,203) | ($528,198,310) |
| 5% | ($89,288,089) | ($86,212,719) | ($90,493,961) | ($101,007,475) | ($303,022,425) | ($449,815,520) |
| 7% | -73,186,448 | -73,737,977 | -77,243,726 | -86,849,794 | -260,549,382 | -387,588,191 |
| 9% | ($60,876,759) | ($63,776,496) | ($66,615,641) | ($75,495,305) | ($226,485,915) | ($337,628,122) |

## 12.6 APPENDIX F: ASSUMPTIONS

| DETAIL | FIGURE | UNIT | |
|---|---|---|---|
| Electrical Cost (on-grid) | 0.09 | $/kWh | |
| Electrical cost (off-grid) O&M | 0.02 | $/kwh | |
| Nominal Interest (Discount) Rate | 7.00% | | |
| Inflation Rate | 2.00% | | |
| Effective Discount Rate | 4.90% | | |
| Data Centre uptime (95%) | 8322 | hours/year | |
| Construction Cost per sq ft | 300 | $/sq ft | |
| Amount of space 'freed' | 10,000 | sq ft | |
| Amortization of freed space | 5 | | |
| Waste heat utilization (6 months) | 50% | | |
| PUE (current) | 2.50 | | |
| PUE (proposed) | 2 | | |
| Depreciation of Building/IT Assets | 15 | years | |
| Depreciation of Upgrades | 10 | years | |
| Time Period of CBA | 10 | years | |
| IT Growth | 7% | annual compound | |
| Total Electrical Demand 2009 | 2300 | kw | |
| Contingency | 15% | | |
| Green Power Premium | $0.03 | $/kwh | alternative is to purchase carbon offsets at $25/tonne, but is cheaper |
| Carbon credit value | $10.00 | $/tonne CO2e | |
| Cash Value for offsets | $2,510,000 | | best case scenario; Alberta to carbon-neutral facility |
| GHG emissions factor, Alberta | 0.82 | | |
| O&M costs, Hydro Electricity | 0.84 | cents/kwh | http://www.eia.doe.gov/cneaf/electricity/epa/epat8p2.html |
| Shadow Price of Carbon | $83.00 | $/tonne CO2e | UK Dept of Energy and Climate Change, http://www.decc.gov.uk/en/content/cms/what_we_do/lc_uk/valuation/valuation.aspx |
| Include SPC | 1 | 1 or 0 (Yes or No) | |
| Interest Loan Payment | 5.75% | | |

## 12.7 APPENDIX G: SAMPLE RELOCATION COSTS

| GHG EMISSIONS FACTOR | NPV OF CARBON OFFSETS | NPV CARBON CREDITS | RELOCATION + CARBON OFFSETS - CARBON CREDITS | NPV CARBON OFFSETS - CREDITS (10 YEARS) |
|---|---|---|---|---|
| 0.01 | $46,402 | $17,520 | 2,018,458 | $18,458 |
| 0.02 | $92,804 | $35,040 | 2,036,916 | $36,916 |
| 0.03 | $139,205 | $52,560 | 2,055,374 | $55,374 |
| 0.04 | $185,607 | $70,080 | 2,073,832 | $73,832 |
| 0.05 | $232,009 | $87,600 | 2,092,290 | $92,290 |
| 0.06 | $278,411 | $105,120 | 2,110,748 | $110,748 |
| 0.07 | $324,812 | $122,640 | 2,129,206 | $129,206 |
| 0.08 | $371,214 | $140,160 | 2,147,664 | $147,664 |
| 0.09 | $417,616 | $157,680 | 2,166,122 | $166,122 |
| 0.1 | $464,018 | $175,200 | 2,184,580 | $184,580 |
| 0.11 | $510,420 | $192,720 | 2,203,038 | $203,038 |
| 0.12 | $556,821 | $210,240 | 2,221,496 | $221,496 |
| 0.13 | $603,223 | $227,760 | 2,239,954 | $239,954 |
| 0.14 | $649,625 | $245,280 | 2,258,412 | $258,412 |
| 0.15 | $696,027 | $262,800 | 2,276,870 | $276,870 |
| 0.16 | $742,429 | $280,320 | 2,295,328 | $295,328 |
| 0.17 | $788,830 | $297,840 | 2,313,786 | $313,786 |
| 0.18 | $835,232 | $315,360 | 2,332,244 | $332,244 |
| 0.19 | $881,634 | $332,880 | 2,350,701 | $350,701 |
| 0.2 | $928,036 | $350,400 | 2,369,159 | $369,159 |
| 0.21 | $974,437 | $367,920 | 2,387,617 | $387,617 |
| 0.22 | $1,020,839 | $385,440 | 2,406,075 | $406,075 |
| 0.23 | $1,067,241 | $402,960 | 2,424,533 | $424,533 |
| 0.24 | $1,113,643 | $420,480 | 2,442,991 | $442,991 |
| 0.25 | $1,160,045 | $438,000 | 2,461,449 | $461,449 |
| 0.26 | $1,206,446 | $455,520 | 2,479,907 | $479,907 |
| 0.27 | $1,252,848 | $473,040 | 2,498,365 | $498,365 |
| 0.28 | $1,299,250 | $490,560 | 2,516,823 | $516,823 |
| 0.29 | $1,345,652 | $508,080 | 2,535,281 | $535,281 |
| 0.3 | $1,392,053 | $525,600 | 2,553,739 | $553,739 |
| 0.31 | $1,438,455 | $543,120 | 2,572,197 | $572,197 |
| 0.32 | $1,484,857 | $560,640 | 2,590,655 | $590,655 |

## 12.8 APPENDIX H: ADDITIONAL CONSTRAINTS ON SCENERIOS

The following details outline concerns or constraints related to the feasibility of scenario 4a, a network of data centres.

### High Capital Costs/Low Utilization

For scenarios in which data centres are replicated, all associated capital and ongoing operating costs will be multiplied by the number of data centres. Some data centres will sit idle when the renewable energy source is unavailable or conversely when multiple sites have energy capacity but only one is required. Low utilization of capital resources will result, and with estimated costs ranging from $12,000 to $22,000 per KW, per the Uptime Institute, this represents an inefficient use of capital investments. Additional costs and complexity will also be required to manage redundancy of data between locations.

### Embodied Emissions in Construction/Net Positive Impact

Replicating data centres in multiple locations creates negative environmental impacts from each construction site. In order to net out or negate the embodied emissions from constructing additional data centres, the data centre/renewable energy project would need to replace a dirty electricity source (high emissions intensity) in locations such as Alberta, Nova Scotia, or Saskatchewan. Building a network of data centre nodes to displace electricity emissions in regions like BC or Ontario would never net back a positive carbon gain based on the embodied construction emissions and the expected lifetime of a data centre. In other words, relocating data centres to a new low-carbon facility only nets a positive environmental impact if the data centre is moving from a high emissions intensity region to a low intensity region.

### Redundancy and Availability Issues

Maintaining and operating a network of data centre nodes created additional complexity. It is possible, though unlikely, that all renewable energy sources could be unavailable at the same time due to their intermittency, There are a few ways to handle this situation, including building at least one data centre that connected to the grid, or having backup power such as diesel generation, but both involve additional capital investments or negative environmental impact through increased construction or GHG emissions.

### Economic Impact of Investment, Inefficiencies

A scenario with multiple remote renewable energy/ data centre locations is inefficient because not all energy produced from the renewable sites will be harnessed at the data centre. If both a run-of-river project and a wind farm are producing energy at the same time, but only one data centre is required to be running, the excess energy will be wasted since no transmission lines exist and the excess capacity cannot be sent anywhere. Renewable energy is best harnessed when combined on a grid, to reduce intermittency and aggregate supply and risk. Investments in renewable energy projects can be better maximized without having to build multiple data centres.