Telecom Advisory Services LLC

COMPARATIVE ASSESSMENT OF ENERGY PRODUCTIVITY OF **CLOUD COMPUTING AND INFORMATION TECHNOLOGY IN CANADA**

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EXECUTIVE SUMMARY

The objective of this study was to examine the role of cloud computing as a key component of the Information Technology (IT) industry in shaping energy consumption patterns in Canada. The transformative power of IT in modern economies extends significantly into all economic sectors, including those most concerned with energy and environmental management. Accordingly, while the massive adoption of IT across individuals, governments, and enterprises can potentially drive a paradigm shift in energy consumption, it also offers a path to enhanced efficiencies. However, these advances are not without their potential drawbacks since the digital era also imposes a surge in energy demand. This is why it is necessary to conduct robust empirical analysis to identify the overall impact on aggregate energy implications of the migration to IT-intensive economies. In this context, this study is aimed to provide evidence that the energy consumed by cloud computing in particular, and the IT industry in general, while high, is more economically productive than that of other sectors (in other words, it produces more added value per unit of energy consumed). Along those lines, the countries that foster the deployment of cloud computing data centers and accelerate their migration to an IT-intensive economy should be highly energy productive, which means that the energy consumed can have an additional impact on economic growth and consumer welfare.

The study focus is on the comparative assessment of energy productivity across sectors in Canada, measuring the total economic value gained from using a unit of energy. The study's overarching conclusion is that **cloud computing is highly energy productive, and that the IT sector is more energy-productive than other sectors, when measured as output per unit of energy consumed.** Additionally, the study measures the impact of hyperscalers' data centers on energy productivity. The conclusions are summarized as follows:

- **Energy productivity of a country's economy, measured as Gross Value Added[1] (GVA) by Megawatt hour of energy consumed, has been found to be positively associated with the percent of public and private organizations adopting cloud computing.** An econometric model that studied the link between energy productivity and cloud adoption among Canadian sectors[2] indicates that **10% increase of cloud adoption will yield an increase in energy productivity of 2.5% (for an average economic sector, this represents a yearly gain equivalent to CAD 25.4 per MWh**

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[1] Gross Value Added is a key indicator in national accounts and is used to estimate how much industries contribute to the economy. It is also a proxy for Gross Domestic Product (GDP) in the output approach to measuring GDP.

[2] Accommodation and food services, Beverage and tobacco product manufacturing, Cement and concrete product manufacturing, Chemical manufacturing, Clothing and leather and allied product manufacturing, Computer and electronic product manufacturing, Construction, Educational services, Furniture and related product manufacturing, Information and cultural industries, Machinery manufacturing, Miscellaneous manufacturing, Offices, Other services (except public administration), Printing and related support activities, Retail trade, Textile and textile product mills, Transportation equipment manufacturing, Truck transportation, Wholesale trade, Wood product manufacturing.

of electricity consumed).[3] This effect can be demonstrated with data from some specific industries (Table A):

Table A: Canada: Economic gains on energy productivity yielded by an increase of 10% in cloud adoption

Sector	Economic gains per MWh (CAD)	Overall economic gains (CAD Million)
IT	$ 246.83	$ 1,668.39
Accommodation and food services	$ 37.72	$ 937.69
Machinery manufacturing	$ 84.53	$ 392.90
Wholesale trade	$ 163.29	$ 2,868.13
Textile	$ 28.81	$ 30.68

Sources: Comprehensive Energy Use Database (Government of Canada); Statistics Canada; Telecom Advisory Services analysis

A similar effect can be demonstrated at the provincial level. An increase in 10% in cloud adoption within an average province yields CAD 7,479 million (see Table B):

Table B: Canada: Economic gains resulting from an increase of 10% in cloud adoption

Province	Economic gains per MWh (CAD)	Overall economic gains (CAD Million)
Atlantic provinces	$ 27.10	$ 2,820.42
Quebec	$ 27.84	$ 10,416.42
Ontario	$ 36.41	$ 20,241.46
Manitoba	$ 26.75	$ 1,656.89
Saskatchewan	$ 15.67	$ 1,808.37
Alberta	$ 12.71	$ 7,871.25
British Columbia and Territories	$ 31.26	$ 7,536.41
Average	$ 25.39	$ 7,478.75

Sources: Comprehensive Energy Use Database (Government of Canada); Statistics Canada; Telecom Advisory Services analysis

The overall economic gains represent the increase in GDP for the country as a whole. Why do cloud service adoption drives an improvement of an entire country energy productivity? Because of the optimization in the supply of IT services. Energy productivity can increase further every year by increasing cloud penetration.

[3] *The estimations presented in this study correspond to year 2021 (due to data availability), however, they can be considered as representative for current periods as energy consumption is largely related to sectoral structure that varies little over time.*

- On the other hand, **energy productivity of a country's economy also depends on the supply of cloud services.** The deployment of hyperscaler data centers turns out to have also a significant positive effect in terms of increased energy productivity. **A new availability zone[4] being deployed in Canada generates an average increase in sector energy productivity of 1.6% (this figure is equivalent to CAD 1.1 billion for the case of the IT industry).** Moreover, we also found evidence confirming that a new availability zone being deployed in Canada will generate an increase of energy productivity beyond the country boundaries, benefiting also neighboring economies. Why do cloud service providers deployment drive an improvement of energy productivity? Because of the optimization in the supply of IT services through economies of scale.

Beyond the specific effect of cloud computing, the IT sector, which is often regarded as a heavy energy consumption sector, exhibits an economic output per energy consumed that is much higher than that of other industries. On a national basis, the real Value Added (VA)[5] of the IT industry[6] per MWh consumed in Canada is CAD 10,450, while the same metric for the agricultural sector is CAD 450, for the industrial sector is CAD 370, and for transportation is CAD 116. Data from all Canadian regions consistently indicates that the IT industry is the most energy productive. Consequently, regions with a large IT sector appear to be those with the largest values in energy productivity. For example, **the regions with the largest IT industries are Ontario and British Columbia, being at the same time those with the highest energy productivity (Ontario: CAD 1,456.6 per MWh, and British Columbia: CAD 1,250.3 per MWh).** All this evidence seems to suggest that the IT sector is among the leaders in terms of energy productivity, and that a larger share of this industry in the economy of a province is associated with higher energy productivity overall.

The public policy implications of this evidence are clear:

- Promoting the adoption of cloud computing services across firms will also increase energy productivity (as it reduces costs per value added) and contribute positively to the environment and ultimately the country competitiveness.

- The presence of availability zones proves that the benefits of cloud computing data centers are significant despite being infrastructures with large consumption of energy.

- Country development of the IT sector yields, in addition to the conventional competitiveness benefits, the environmental effect of added energy productivity.

[4] An "availability zone" is a geographic location where a cloud service provider operates a data center. This should not be confused with the term "cloud regions" which may contain multiple "availability zones". While a availability zone may comprise multiple data centers, no two availability zones share the same data center. Therefore, each availability zone is self-contained and physically isolated from other availability zones in the same region to provide additional fault tolerance and resiliency.
[5] Real value added is evaluated in 2017 chained Canadian dollars
[6] The IT industry is defined in Canadian national accounts as "Information and cultural industries"

1. INTRODUCTION

In the current era of unprecedented technological growth, energy efficiency and energy productivity have emerged as critical needs for achieving global sustainability combined with economic growth. Recent trends in global warming, have been raising concerns over environmental degradation, pushing firms and governments alike to examine their energy strategies, focusing on efficiency to mitigate climate change impact.

Consequently, in recent years, energy sustainability has turned into a proactive, innovative, and integral aspect of modern energy management. Factors such as technological innovation, economic considerations, and environmental awareness have been driving this shift. The aim of most governments to promote green agendas aiming for environmental sustainability underscores the need for efficient energy utilization, making it a central topic in public policy agendas. However, these objectives should be combined with economic growth as fostered by sectors that maximize value added per unit of energy consumed.

In this context, the objective of this study is to examine the role of cloud computing in the context of the IT industry in shaping the productivity of energy consumption patterns. The transformative power of IT in modern economies extends significantly into all economic sectors, including those most concerned with energy and environmental management. Accordingly, the massive adoption of IT across individuals, governments, and enterprises can potentially drive a paradigm shift in energy consumption. However, these advances are not without their potential drawbacks since the digital era also imposes a surge in energy demand. This is why it is necessary to conduct robust empirical analysis to identify the overall effect in aggregate energy sustainability of the migration to IT-intensive economies. In this context, this study aims to provide evidence that the energy consumed by the IT industry, specifically by cloud computing, while high, is more economically productive than that of other sectors (in other words, it produces more added value per unit of energy consumed). Along those lines, the industries that accelerate their migration to an IT-intensive economy should be highly energy productive.

The study is structured in five chapters. In Chapter 2, we frame the hypotheses to be tested empirically in the study. Moving on to the econometric analysis, Chapter 3 presents the empirical specification and data used in two models to test the causality between the adoption as well as supply of cloud services and energy productivity. Chapter 4 develops a comparative analysis of energy productivity across Canadian sectors and regions, with the specific focus of comparing the IT sector with other industries. Finally, Chapter 5 presents the study conclusions and draws the policy implications. A review of the available research literature of the topic under study, the data sources for the descriptive analyses and detailed review of the econometric models are included in the appendices.

2. STUDY THEORETICAL FRAMEWORK AND HYPOTHESES

Research on energy productivity, and the particular role of the IT industry and data centers has been conducted for a number of years (see Appendix A. Review of the Research Literature). The principal objective of this study is to advance such research, examining the role of cloud computing, in the context of the IT industry, in making Canadian industries grow while increasing the energy productivity of the economy. In that sense, while recognizing that digital technologies are heavy energy consumers, **our purpose is to demonstrate that, when measured by output per energy consumption, the energy productivity of the IT sector, specifically of cloud computing, is higher than in other sectors.**

Along these lines, and based on the research literature review, we put forward four study hypotheses:

- The increase in cloud adoption by public and private organizations is a driver of energy productivity.

- In particular, large cloud service providers, a key infrastructure of the information economy, are expected to be associated with higher energy productivity. Energy productivity also depends on the size of cloud service providers. Hyperscalers, while being high energy consumers, can lead at the same time to greater energy productivity through economies of scale and advanced service optimization, not only within the countries they are located, but also in neighboring ones at a regional level.

- Moving to a more general level, the IT industry across Canadian regions depicts the highest energy productivity, when measured as Gross Value Added (GVA) per MWh consumed. While recognizing the heavy energy consumption of the IT sector, its economic output per energy consumed is higher than that of other sectors analyzed.

- Consequently, province economies with a large IT sector and presence of several large technology providers fulfill by far the largest value in energy productivity: considering the higher economy output per energy consumed for the IT sector, the provinces that exhibit higher share of GDP for the IT sector, yield higher energy productivity.

These hypotheses will be tested with two methodologies as indicated below:

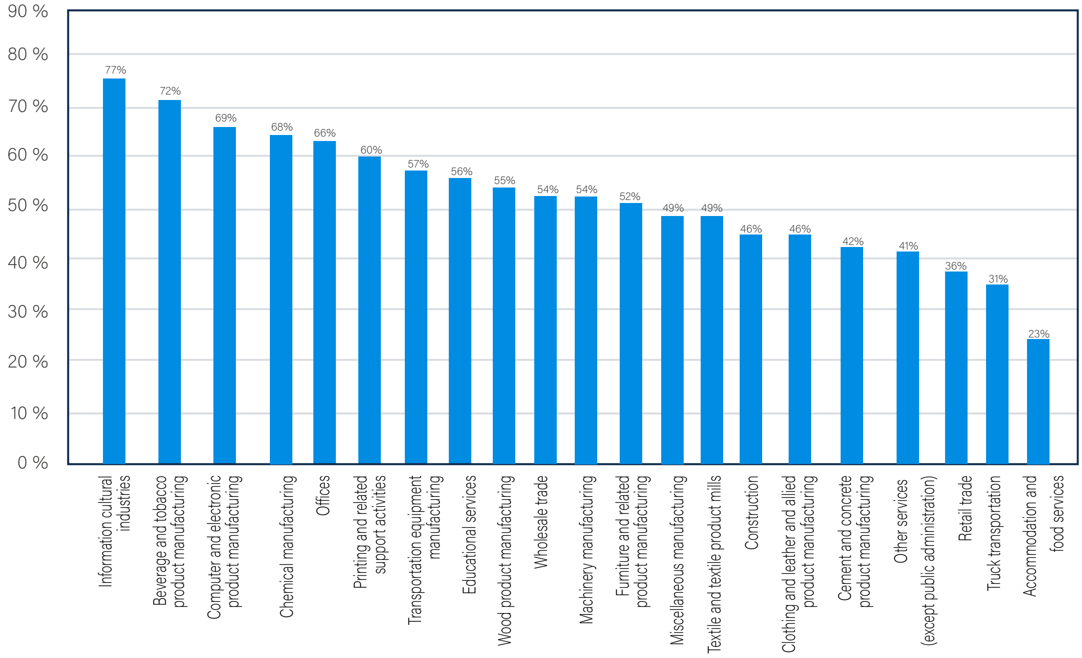
- Econometric models analyzing the impact of cloud adoption and cloud services supply on energy productivity.

- A descriptive analysis comparing economic output per energy consumed for different sectors, comparing the IT industry with other sectors in Canada.

3. ENERGY PRODUCTIVITY OF CLOUD COMPUTING

This chapter provides evidence on the impact of a technology infrastructure that is central to the IT sector: cloud computing. Cloud adoption by sector, as reported by the Survey of Digital Technology and Internet Use in the Statistics Canada platform for 2021 (last year available), is detailed in Graphic 3-1.

Graphic 3-1. Canada: Cloud adoption by sector (% of enterprises) (2021)

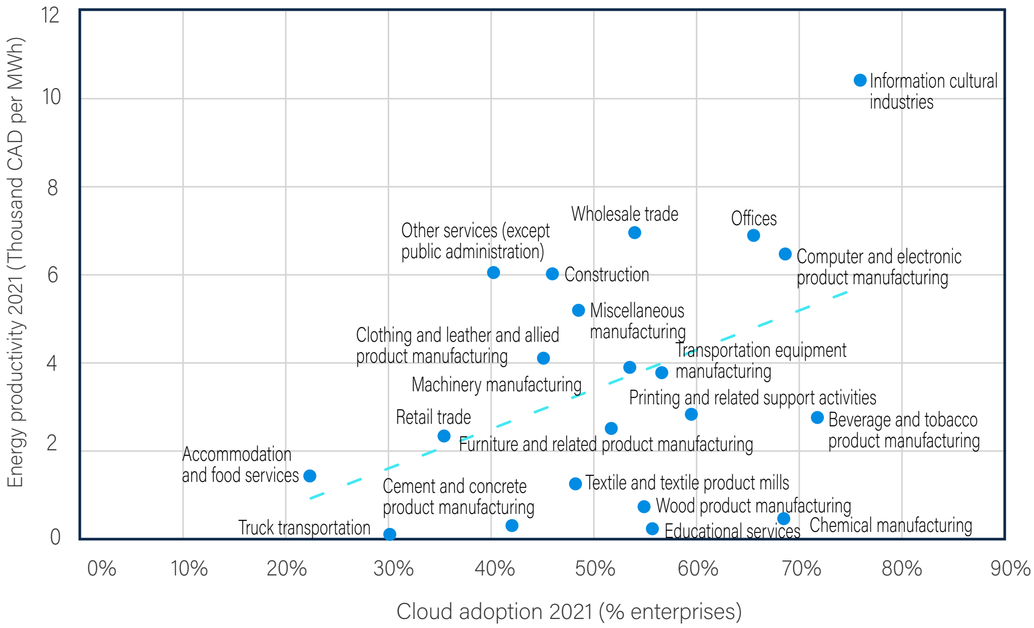


Source: Survey of Digital Technology and Internet Use (Statistics Canada)

As suggested in Graphic 3-1, highest cloud adoption is found in the IT sector (identified in Canadian national accounts as Information and cultural industries), followed by some manufacturing industries (such as beverage and tobacco, computer and electronic equipment, and chemicals). At the other end, the lowest adoption is reported for the accommodation and food services sector.

Preliminary statistical evidence indicates a positive link between cloud computing and energy productivity by sector, as plotted in Graphic 3-2: industries with higher cloud adoption (measured by business adoption) are associated with a higher level of energy productivity (measured as value added per MWh in thousand CAD).

Graphic 3-2. Canada: Cloud adoption and energy productivity (2021)



Sources: Comprehensive Energy Use Database (Government of Canada); Survey of Digital Technology and Internet Use; Statistics Canada; Telecom Advisory Services analysis

Graphic 3-2 also shows that sectors with similar level of cloud adoption exhibit different values of energy productivity, which indicates that other factors appear to be at work. A regression analysis with control variables allows generating a more accurate picture of this relationship.[7]

These models consist in regressing energy productivity on cloud adoption, cloud availability zones, and a series of control variables. Results of the most conservative specification indicate that **an increase in 10% in cloud adoption will yield a 2.5% increase in energy productivity (this means that for an average economic sector, this effect represents a yearly gain equivalent to CAD 25.4 per MWh of electricity consumed).**[8] This effect can be demonstrated to exist in several sectors, although the highest impact takes place in the Canadian IT industry (Table 3-1):

[7] Appendix B presents the econometric model structure, as well as the descriptive data used in the models, while Appendix C contains the models results. The model is presented in Table C-1 in Appendix C.
[8] The presence of fixed effects and additional controls in the model validates the hypothesis that cloud computing has a positive impact on energy productivity.

Table 3-1: Canada: Economic gains from energy productivity after an increase in 10% in cloud adoption

Sector	Economic gains per MWh (CAD)	Overall economic gains (CAD Million)
IT	$ 246.83	$ 1,668.39
Accommodation and food services	$ 37.72	$ 937.69
Machinery manufacturing	$ 84.53	$ 392.90
Wholesale trade	$ 163.29	$ 2,868.13
Textile	$ 28.81	$ 30.68

Sources: Comprehensive Energy Use Database (Government of Canada), Statistics Canada Telecom Advisory Services

A similar effect can be demonstrated at the provincial level. An increase in 10% in cloud adoption within an average province yields CAD 7,479 million (see Table 3-2):

Table 3-2: Canada: Economic gains from energy productivity after an increase in 1% in cloud adoption

Province	Economic gains per MWh (CAD)	Overall economic gains (CAD Million)
Atlantic provinces	$ 27.10	$ 2,820.42
Quebec	$ 27.84	$ 10,416.42
Ontario	$ 36.41	$ 20,241.46
Manitoba	$ 26.75	$ 1,656.89
Saskatchewan	$ 15.67	$ 1,808.37
Alberta	$ 12.71	$ 7,871.25
British Columbia and Territories	$ 31.26	$ 7,536.41
Average	$ 25.39	$ 7,478.75

Sources: Comprehensive Energy Use Database (Government of Canada), Statistics Canada Telecom Advisory Services

Another econometric model was developed to estimate the effect of cloud availability zones on energy productivity. Data centers operated by large cloud service providers (hyperscalers) are expected to generate greater energy productivity through economies of scale and advanced optimization, which individual, traditional data centers are typically unable to achieve. The nature of cloud infrastructure is such that hyperscalers' data centers -located in "availability zones"- often serve multiple territories beyond their specific location..[9] These locations are chosen based on factors such as connectivity, electricity supply stability, and legal-economic environments, causing a spillover of energy productivity. The impact of a cloud computing data center on energy productivity can be measured as follows: **a new availability zone being deployed in a particular Canadian province is expected to generate an increase in sector energy productivity of 1.6% (for example, this amount is equivalent to CAD 1.1 billion for the IT industry).**

[9] *As defined in the Executive Summary, an "availability zone" is a geographic location where a cloud service provider operates a data center. This should not be confused with the term "cloud regions" which may contain multiple "availability zones". While a availability zone may comprise multiple data centers, no two availability zones share the same data center. Therefore, each availability zone is self-contained and physically isolated from other availability zones in the same region to provide additional fault tolerance and resiliency.*

Moreover, we also found evidence confirming that a new availability zone being deployed in Canada will generate an increase of energy productivity beyond the country boundaries, benefiting also neighboring economies.[10] However, while proven on cross-country panel data, this effect could not be verified in Canada due to data limitations.

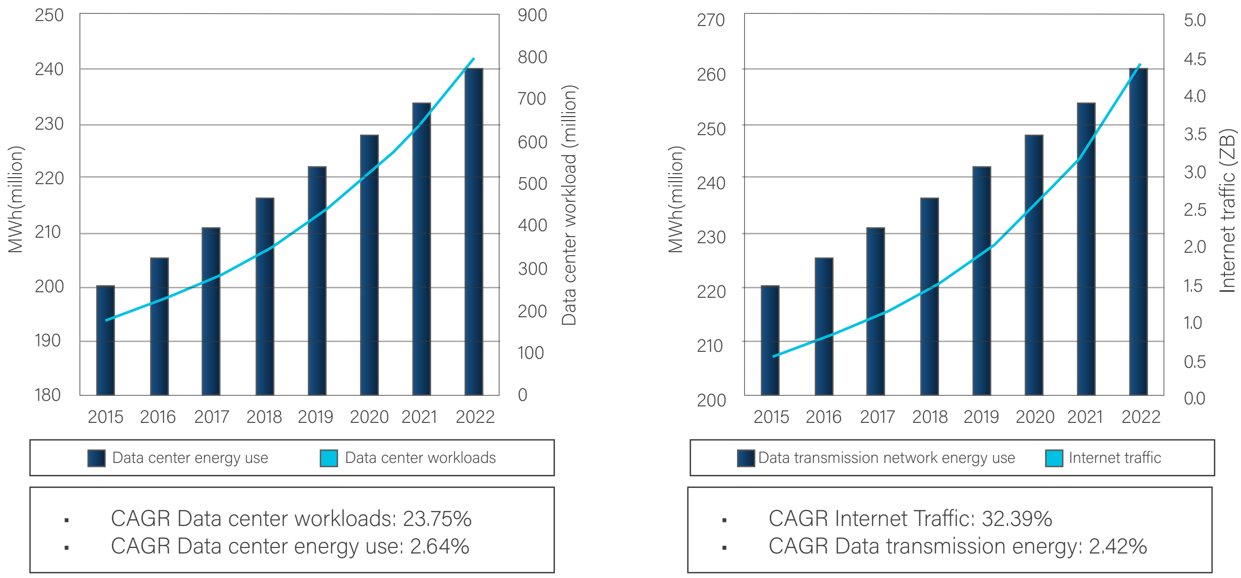
Our results are clearly pointing out that increases in cloud adoption are associated with improvements in energy productivity, thus reinforcing the critical role of this infrastructure for development as identified in prior research. Our results have proven to be robust to the addition of fixed effects and control variables.

[10] *This is verified in the cross-country econometric model presented in Appendix D*

4. ENERGY PRODUCTIVITY OF THE IT SECTOR

The prior analysis confirmed the impact of cloud computing on energy productivity. Given the importance of this infrastructure within the IT industry, it is also relevant to investigate whether canadian provinces that exhibit a higher share of their GDP related to IT industries also denote higher energy productivity. **In the aggregate, the recent trends in terms of global internet traffic growth and data centers deployment indicate that energy productivity in the IT sector is increasing rapidly.** As indicated in Graphic 4-1, internet traffic and datacenter workloads have been increasing at a much faster pace than the respective energy consumption in each field.

Graphic 4-1. World: Evolution of global energy consumption by IT component



Sources: IEA, Telecom Advisory Services analysis

The evidence presented in Graphic 4-1 is the result of the so-called Moore's law (Montevecchi et al., 2020), where diverse performance metrics in the digital economy usually evolve much faster than in traditional economic sectors.

The objective of the following analysis is to generate evidence on the relationship between the size of the IT industry and energy productivity and compare it with that of other sectors in Canada. For this purpose, we compiled data for the agriculture, industrial and transportation sector in Canada, relying on a dataset for 2021. By estimating the real value added on the energy consumption we calculate the energy productivity for the IT sector across Canadian provinces (see Table 4-2).

Table 4-2. Canada: energy productivity of the IT sector (2021)

Region	Real value added of IT sector (thousand CAD)	Energy consumption of IT sector (MWh)	Energy Productivity of IT sector (thousand CAD per MWh)
Atlantic provinces	$ 3,108,738	277,777.78	$ 11.19
Quebec	$ 12,109,429	1,472,222.22	$ 8.23
Ontario	$ 33,471,030	2,638,888.89	$ 12.68
Manitoba	$ 1,823,248	250,000.00	$ 7.29
Saskatchewan	$ 1,350,206	222,222.22	$ 6.08
Alberta	$ 6,905,282	1,305,555.55	$ 5.29
British Columbia and Territories	$ 9,739,405	388,888.88	$ 25.04
Total	$ 68,507,338	6,555,555.54	$ 10.45

Source: Comprehensive Energy Use Database (Government of Canada), Statistics Canada

Having estimated the energy productivity for the IT sector, we follow the same approach to calculate the energy productivity of other industries for comparison purposes (Table 4-3).

Table 4-3. Canada: Energy productivity by economic sector (2021)

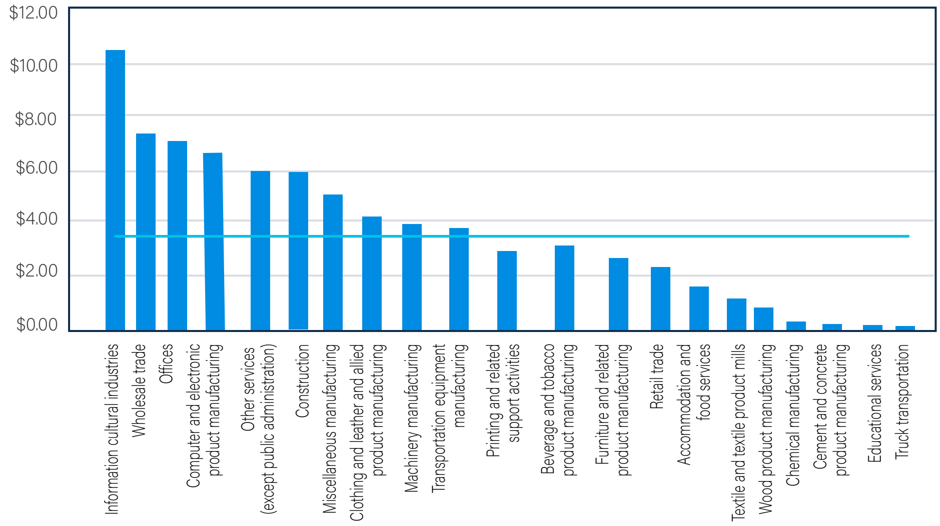
Country	Energy productivity (VA per MWh in thousand CAD)			
	Agricultural sector	Industry sector	Transport sector	IT sector
Atlantic provinces	$ 1.66	$ 0.24	$ 0.08	$ 11.19
Quebec	$ 0.72	$ 0.35	$ 0.10	$ 8.23
Ontario	$ 0.46	$ 0.54	$ 0.11	$ 12.68
Manitoba	$ 0.41	$ 0.48	$ 0.14	$ 7.29
Saskatchewan	$ 0.22	$ 0.28	$ 0.09	$ 6.08
Alberta	$ 0.33	$ 0.27	$ 0.15	$ 5.29
British Columbia and Territories	$ 0.66	$ 0.24	$ 0.13	$ 25.04
Total	$ 0.45	$ 0.37	$ 0.12	$ 10.45

Source: Comprehensive Energy Use Database (Government of Canada), Statistics Canada

In all the provinces and regions considered, the IT industry is the most energy productive.

In Graphic 4-2, we present a more disaggregated sector definition for the country as a whole.

Graphic 4-2. Canada: Average energy productivity by sector 2021 (real VA per MWh in thousand CAD)

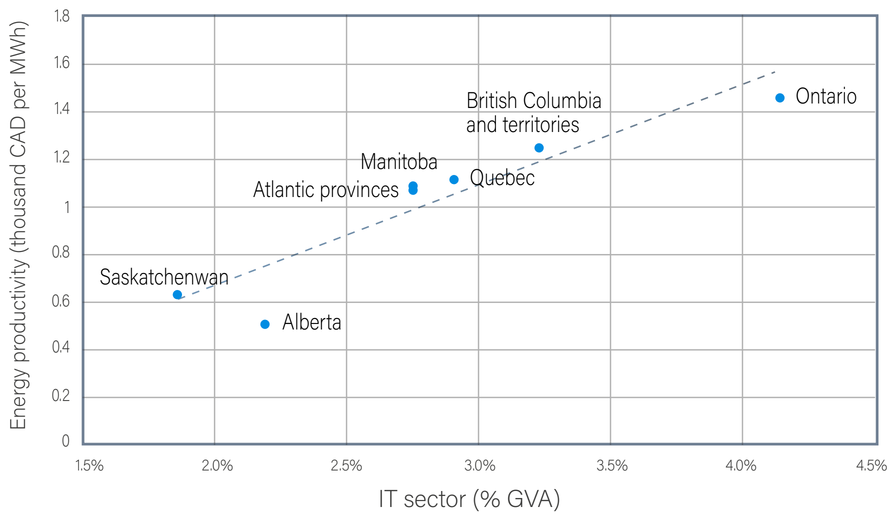


Sources: Comprehensive Energy Use Database (Government of Canada); Statistics Canada; Telecom Advisory Services analysis

Clearly, the IT industry stands out as the economic sector with the highest level of productivity among those analyzed.

If we consider the average energy productivity by region along with the share of the IT industry on their economy, we can conclude that on average, **a higher share of the economy of IT (measured as share of value added) is associated with higher energy productivity,** as depicted in Graphic 4-3.

Graphic 4-3. Canada: IT sector share and average energy productivity



Sources: Comprehensive Energy Use Database (Government of Canada); Statistics Canada; Tdelecom Advisory Services analysis

Evidence from Graphic 4-3 indicates that **the region with the largest IT industry is Ontario, being at the same time that with the largest energy productivity (CAD 1,456.58 per MWh). Beyond Ontario, British Columbia and Quebec follow next.**

All this evidence seems to suggest that the IT sector is among the leaders in terms of energy productivity, and that a larger share of this industry in the economy seems to be associated with higher energy productivity overall.

5. CONCLUSION

The purpose of this research has been to provide evidence on the critical importance of cloud computing and the IT sector in general for driving energy productivity. In doing so, the study focus has been on the comparative assessment of energy productivity, which measures the total economic value gained from using a unit of energy.

Our results were clear in pointing out that increases in cloud adoption are associated with improvements in energy productivity, thus reinforcing the critical role of the technology for development, evidence that has been already identified in prior research. An econometric model regressing energy productivity over cloud adoption for Canada indicates that **10% increase of cloud adoption will yield an increase in energy productivity of 2.5% (for an average economic sector, this represents a yearly gain equivalent to CAD 25.4 per MWh of electricity consumed). Furthermore, the deployment of cloud computing hyperscalers turns out to have also a significant positive effect in terms of increased energy productivity. Results suggest that a new availability zone being deployed generates an increase in energy productivity of 1.6%.**

Additionally, the study relying on Canadian data has shown that the energy consumed by the IT sector is more energy-productive than that of other sectors. On a national basis, the real VA of the IT industry per MWh consumed is CAD 10,450, while the same metric for the agricultural sector is CAD 449.5, for the industrial sector is CAD 370.1, and for transportation is CAD 116.2. The IT industry throughout the country is the most energy productive. Consequently, the provinces with a large IT sector appear to be those with the largest values in energy productivity. **The regions with the largest IT industries are Ontario and British Columbia, being at the same time those with the highest energy productivity.** All this evidence seems to suggest that the IT sector is the leader in terms of energy productivity, and that a larger share of this industry in the economy of a province seems to be associated with higher energy productivity overall.

The public policy implications of this evidence are clear. First, country development of the IT sector yields, in addition to the conventional competitiveness benefits, the environmental effect of added energy productivity. Second, promoting the adoption of cloud computing services across firms and individuals will increase energy productivity (as it reduces costs per value added) and will also contribute positively to the environment and ultimately competitiveness. Third, the presence of cloud computing data centers contributes to benefits in terms of energy productivity.

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APPENDIX A. REVIEW OF THE RESEARCH LITERATURE

A.1. Energy efficiency, energy productivity and their drivers

In line with most public policy agendas worldwide that are increasing their efforts towards sustainable economic growth, energy efficiency and energy productivity have been raised as an important concern in the research literature. For example, the study by Atalla and Bean (2017) focused on the analysis of the determinants of energy productivity, defined as the ratio of economic output per unit of energy consumed. Using a database of 39 countries for the period 1995-2009, the authors employ various analytical techniques to identify the determinants of energy productivity. One key insight drawn from this analysis is that **most country-level increases in energy productivity were found to take place due to improvements within sectors rather than shifts in economic structure**. In addition, the authors found that the highest rate of improvement in energy productivity was registered in former communist countries that have been undergoing economic liberalization processes through that period. Their results also point to income per capita and energy prices as drivers of energy productivity, while a greater share of output from industry was found to be associated with lower energy productivity levels.

Coinciding partially with some of the conclusion of the prior study, Sineviciene et al. (2017) analyzed the drivers of energy efficiency during the period 1996–2013 in Eastern Europe post-communist economies. Relying on a stochastic frontier function approach and a comparative analysis to examine long-run dynamic relations, the authors point to **GDP growth as a key factor increasing both energy efficiency, while fixed capital formation and the share of industry in the economy are also important drivers. In short, changes in industry structure also appear to play a role in driving improved energy efficiency.** This is partially consistent with the research of Chang and Hu (2010), who developed a total-factor energy productivity index to evaluate the change in regions in China. They found that **factors affecting energy efficiency are linked to economic development, to the electricity share of energy consumption, coupled with the sector structure of the economy**. While this study focuses energy consumption and efficiency rather than energy productivity, by relating these to level of development and the share of different sectors of the economy, it provides an analytical framework of causality that is useful to understand energy productivity.

Turning to an additional perspective, Uwasu et al. (2012) explored the drivers of energy productivity, defined as the ratio of Gross Regional Product and energy input, in China's provinces during the period between 2004 and 2007. The authors disaggregated energy productivity into two attributes: technology use and input factors. On this basis, they estimated energy technology levels, with results showing that disparities exist across the provinces even after controlling for differences in the contribution of input factors to energy productivity, implying **the importance of technological advancements for energy productivity enhancement**. They also argue that investment in technology and the quality of capital can indirectly determine the level of energy productivity.

Song and Zheng (2012) conducted an econometric study using a Chinese provincial-level panel data set for the period between 1995 and 2009, concluding that **while increasing incomes were a substantial factor in driving energy efficiency, energy prices were not a key driver**. They also noted that the growth in urbanization rates presented obstacles to enhancing energy intensity.

In another study covering four decades and examining 75 nations, with a special focus on Latin America, Jimenez and Mercado (2014) analyzed energy intensity trends. Their research revealed that **advancements in energy were mainly due to improvements in energy intensity**[1] **across the economy**. Their econometric evaluation identified that critical factors included rising per capita income, oil prices, and overall economic expansion.

To sum up, the research literature has identified so far, several drivers of energy productivity and efficiency that will be taken into consideration in our empirical work (see table A-1).

Table A-1. General economic drivers of energy productivity and efficiency

Drivers	Research literature
GDP / Income per capita	• Atalla and Bean, 2017 • Sineviciene et al., 2017 • Song and Zheng, 2012 • Jimenez and Mercado, 2014 • Chang and Hu, 2010
Sectoral structure of the economy	• Atalla and Bean, 2017 • Sineviciene et al., 2017 • Chang and Hu, 2010
Fixed capital formation	• Atalla and Bean, 2017 • Sineviciene et al., 2017
Capital quality	• Uwasu et al., 2012
Productivity	• Uwasu et al., 2012
Energy prices	• Atalla and Bean, 2017 • Jimenez and Mercado, 2014
Technological advances	• Uwasu et al., 2012
Urbanization	• Atalla and Bean, 2017 • Song and Zheng, 2012

A.2. Energy productivity and efficiency in the IT sector

The specific role of ICT in driving energy productivity and efficiency has been less researched than general drivers, although the existing evidence provides some important insights regarding the **impact of digital technology on energy efficiency**.

Berkhout and Hertin (2001) identified five domains where ICTs could enhance production efficiency, consequently lowering energy use: (i) Intelligent production processes; (ii) Intelligent creation and operation of goods and services; (iii) Intelligent distribution and logistics, such as enhancing supply chain efficacy or

[1] Energy intensity is defined as the ratio of the total final consumption of energy and the GDP, thereby closer to the term of energy productivity used in this study.

modifying distribution frameworks; (iv) Transforming consumer-producer dynamics through, for instance, mass customization; (v) Restructuring of work organization, like the adoption of remote work practices. In a similar conclusion, Sui and Rejeski (2002) have characterized the positive environmental impact of ICT as the "three D's for the new economy": **the transition from physical to digital formats (they call it dematerialization), the move towards a less energy-demanding economy (decarbonization), and reduced necessity for physical movement due to digital alternatives (demobilization)**. Further, Beier et al. (2018) argued that the adoption of the Internet of Things (IoT) in industries can pave the way for more resource-conservative production, enhanced recycling methodologies, and anticipatory maintenance routines. In addition, some authors have argued that smart energy consumption feedback systems, supported by a range of digital technologies, have the capability to drastically diminish energy requirements within residential areas (Buchanan et al, 2015; Jensen et al, 2016; Malmodin and Coroama, 2016; Nilsson et al, 2018).

Other authors present a more nuanced view of the positive impact of ICT on energy efficiency. For example, Lange et al. (2020) examined four primary effects linking ICT deployment and energy efficiency: (i) the direct energy consumption stemming from ICT production and usage, (ii) the potential energy efficiency gains due to digitalization, (iii) the economic growth spurred by enhanced productivity, and (iv) the shift towards a more service-oriented economy with the proliferation of ICT services. The authors main conclusion is that while certain aspects of digitization promote energy efficiency, these are overshadowed by the increased energy demands brought about directly by ICT and indirectly through economic growth stimulated by digitization. Consistently with this conclusion, Batool et al. (2022) explore the relationship between ICT and energy consumption across various sectors in China. Their research uses a threshold regression analysis, considering ICT as a critical point influencing energy consumption behavior within residential, industrial, and transport sectors for the period 1990-2021. The study unveiled an asymmetric impact of ICT on energy consumption, with varying outcomes across different sectors. One of the authors' critical insights is **the potential for ICT to generate rebound effects[2] — situations where increased efficiency leads to more energy consumption due to behavioral or systemic responses**. However, there are a number of studies and simulations that indicate that, when considered in the aggregate, the rebound effects are too small in relation to the efficiency effects.[3]

A.3. Energy productivity and efficiency in cloud computing

[2] The term rebound is used to describe effects which prevent the potential savings resulting from efficiency increases from being realized (at all or in full). It is measured as the percentage of the theoretical savings potential of efficiency increases which cannot be saved due to consumer behavior. Direct rebound results in an increased demand for the same good due to, for example, lower prices. Indirect rebound measures increased demand for other goods driving energy consumption as a result of savings in consumption of primary good.

[3] See Gillingham, K., M. Kotchen, D. Rapson, G. Wagner, 2013. "The Rebound Effect is Over-played." *Nature*, 493: 475-476. http://www.nature.com/nature/journal/v493/n7433/full/493475a.html In an opposite view, see Brockway and Sorrell (2016).

In recent years, cloud computing has emerged as a transformative force, reshaping how businesses operate and how services are delivered. Massive investments have been conducted recently by global players such as Alibaba, Amazon Web Services, Microsoft, or Google in cloud platforms across the globe, while the share of firms and individuals that purchase cloud services has been increasing steadily through the years. This situation has brought the need to explore the potential of cloud computing not just as a technological innovation but also as a potential tool for energy productivity and efficiency.

The theoretical contribution of cloud computing to energy efficiency lies in the optimized utilization of computing resources and the agility in adopting efficient software solutions. Traditional data centers are known for their high energy consumption, primarily due to underutilization of resources and the need for constant cooling systems (Mastelic and Brandic, 2015). Cloud computing, with its shared resources model, optimizes the use of hardware, thereby increasing the workload per energy unit consumed. This principle allows for significant energy savings compared to traditional computing methods (Fiandrino et al., 2017). Along these lines, the cloud computing shared resources model optimizes the use of hardware, increasing the workload per energy unit consumed. Similarly, another study estimates a technical savings potential of 87% in energy consumption if typical office applications are shifted to the cloud.[4]

Moreover, cloud data centers benefit from economies of scale. Large-scale operations allow for more significant investments in energy-saving technologies, such as advanced cooling systems, renewable energy sources, and state-of-the-art server technology, which smaller data centers might not afford (Vashist and Singh, 2013). The deployment of large cloud hyperscalers contribute to maximize the benefits of economies of scale. For example, research evidence indicates that while hyperscalers are heavy energy consumers, research commissioned by AWS shows that that their infrastructure is 3.6 times more energy efficient than the median of the surveyed US enterprise data centers.[5] Consequently, companies that have migrated to the cloud are expected to report not only reduced operational costs but also decreased energy usage. These savings are most notable in organizations with fluctuating demands, as cloud computing allows them to scale resources up or down based on real-time needs, avoiding the inefficiencies of unused resources.

Despite its potential, achieving energy efficiency through cloud computing is not without challenges. Data centers' energy efficiency varies significantly based on their design, usage, and geographical location. The reliance on renewable energy sources and the effectiveness of cooling technologies are also important factors (Mastelic and Brandic, 2015). Furthermore, the rebound effect discussed above might suggest that the cost savings and efficiencies gained from cloud computing could lead to increased consumption, potentially mitigating some of the environmental benefits. That said, no research has been conducted to date to document the potential impact of rebound effects in cloud computing.

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[4] Masanet, E., Shehabi, A., Ramakrishnan, L., Liang, J., Ma, X., Walker, B., Mantha, P. (2014). *The Energy-efficiency Potential of Cloud-Based Software: A US Case Study*. Berkeley, CA: Lawrence Berkeley National Laboratory.
[5] 451 Research (2019). *The Carbon Reduction Opportunity of Moving to Amazon Web Services*

APPENDIX B. ECONOMETRIC MODELS STRUCTURE AND DESCRIPTIVE DATA

B.1. Econometric model

The empirical specification to estimate the energy productivity for cloud computing is presented in the following equation, where i denotes a specific industry during period t:

$$\log(\text{Energy productivity}_{it}) = \alpha_i + \beta \log(\text{Cloud}_{it}) + \gamma\, Availability\ zones_t + \lambda\, X_{it} + \varepsilon_{it}$$

The dependent variable is energy productivity, which is expected to depend on a sector-level fixed effect (α_i), on cloud adoption, on national-level availability zones, plus the control variables.

The different ICT-related variables aim to address the complexities in the relationship between digital technologies and energy productivity as described in the research literature review. Cloud computing, characterized by on-demand availability, resource pooling, and rapid elasticity, has changed how computing resources are accessed and used. From that perspective, we expect a higher cloud adoption rate across the economy to yield larger energy productivity, although the rebound effect can potentially mitigate so of those positive results, as highlighted in the literature review.

The relevance of cloud computing is not only driven by firms demanding these services (as measured by adoption), but critically on the supply side as well. Hyperscalers, are high energy consumers but at the same time can lead to greater energy productivity through economies of scale and advanced optimizations, which individual, in-premise data centers are typically unable to achieve.

Finally, the term X represents a vector of time-varying control variables that could be associated to different levels of energy productivity, also identified in the literature review above (see section A.1).

B.2. Descriptive data used in the models

A dataset was compiled for 21 economic sectors of Canada[6] covering the years 2019-2021. In Table B-1 we present the set of variables to be used in the empirical analysis.

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[6] Accommodation and food services, Beverage and tobacco product manufacturing, Cement and concrete product manufacturing, Chemical manufacturing, Clothing and leather and allied product manufacturing, Computer and electronic product manufacturing, Construction, Educational services, Furniture and related product manufacturing, Information and cultural industries, Machinery manufacturing, Miscellaneous manufacturing, Offices, Other services (except public administration), Printing and related support activities, Retail trade, Textile and textile product mills, Transportation equipment manufacturing, Truck transportation, Wholesale trade, Wood product manufacturing.

Table B-1. Variables description and main statistics

Variable	Description	Source	Mean	Std. dev.
Energy productivity	Value Added per PJ of energy consumed (in thousand CAD). In constant prices 2017 chained CAD.	Comprehensive Energy Use Database, Statistics Canada	916,366.8	725,440.7
Cloud	Cloud adoption (% enterprises)	Survey of Digital Technology and Internet Use	49.028	14.153
Availability zones	Number of zones in cloud regions	TeleGeography	14.667	3.116
K	Capital stock index	Statistics Canada	105.297	8.238
MFP	Multifactor Productivity	Statistics Canada	98.713	5.948

Source: Telecom Advisory Services analysis

The dependent variable is energy productivity, defined as real VA by PJ of energy consumed (in thousand CAD). VA data was obtained from Statistics Canada, while energy consumption was extracted from the Comprehensive Energy Use Database of Canada.

As for the ICT related variables, cloud adoption is defined as the share of firms using cloud computing services, with data reported by the local Survey of Digital Technology and Internet Use. As data on cloud adoption is only available for 2019 and 2021, we conduct an imputation for 2020 assuming constant compound annual growth rate for the period 2019-2021. Also, we include availability zones, often managed by hyperscalers, are high energy consumers but at the same time can lead to greater energy productivity through economies of scale and advanced optimization.

As for the control variables, it is important to consider a set of time-varying potential drivers of energy productivity in order to correctly isolate the cloud computing variables. First, we must control for the sectoral structure of the economy by introducing sector fixed effects.

Investment in capital has also been identified as a potential driver of energy productivity (Atalla and Bean, 2017; Sineviciene et al., 2017). Economies with high investment intensity should replace their capital stock faster, therefore being expected to have on average newer energy-efficient capital (Atalla and Bean, 2017). We control for this factor by including the fixed capital index by sector (data from Statistics Canada). We also control for productivity by including a MFP measure (also reported by Statistics Canada).

APPENDIX C. ECONOMETRIC MODEL RESULTS

The results for the econometric estimation conducted are presented in Table C-1.

Table C-1. Fixed Effects panel estimation

Dep. var: log(Energy Productivity)	(i)	(ii)	(iii)	(iv)
log(Cloud)	0.249**	0.295***	0.281***	-0.151
	[0.094]	[0.094]	[0.118]	[0.142]
MFP		0.004	0.010**	0.007
		[0.002]	[0.004]	[0.006]
K			0.013*	0.010
			[0.006]	[0.008]
Zones				0.016***
				[0.005]
Sector Fixed Effects	YES	YES	YES	YES
R-squared (within)	0.086	0.104	0.218	0.466
Observations	63	63	63	63

*Note: Robust standard errors in brackets. *** p<0.01, ** p<0.05, * p<0.1*
Source: Telecom Advisory Services analysis

From the results presented in column (i), (ii) and (iii) of Table C-1, we can support the study's first hypothesis that increases in cloud adoption drives energy productivity. Results from column (i) indicate that 10% increase of cloud adoption will yield an increase in energy productivity of 2.5%.

On the other hand, the variable that accounts for availability zones is included in column (iv). After its inclusion, cloud adoption loses significance, as its effect seems to be absorbed by the zone variable. According to its coefficient, a new availability zone deployed will increase energy productivity in 1.6%.

APPENDIX D. ECONOMETRIC MODEL RESULTS FOR CROSS-COUNTRY SAMPLE

In order to understand if there is a cross-country effect from availability zones deployment, we conducted an estimate for 50 countries (including Canada), with the following results presented in Table D-1.

Table D-1. Arellano-Bond Dynamic panel estimation

Dep. var: log (Electricity Productivity)	
Log (Electricity Productivity) $_{t-1}$	0.426*** [0.023]
Log (Cloud penetration)	0.013*** [0.005]
Availability zones	0.001*** [0.000]
W Availability zones	0.015* [0.008]
Log (Agriculture share)	-0.051*** [0.010]
FDI	0.002** [0.001]
Capital Formation	0.005*** [0.001]
Time-trend	YES
Observations	189

*Note: Standard errors in brackets. *** p<0.01, ** p<0.05, * p<0.1*
Source: Telecom Advisory Services analysis

From the results presented in TableD-1, the variable that accounts for availability zones deployed in neighboring countries (W Availability zones) presents a positive and statistically significant coefficient. The quantification of the effect from neighbor countries varies depending on each specific case, but this evidence confirms that a new availability zone being deployed in Canada will generate an increase of electricity productivity on the countries located close to it (for example, in the United States).