Energy Research & Social Science 68 (2020) 101682

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Analysis of the electricity demand trends amidst the COVID-19 coronavirus pandemic

Azzam Abu-Rayash*, Ibrahim Dincer

Clean Energy Research Laboratory, Faculty of Engineering and Applied Science, Ontario Tech University, 2000 Simcoe Street North, Oshawa, Ontario L1H 7K4, Canada

ARTICLE INFO

Keywords:
Smart city
COVID-19 pandemic
Energy conservation
Electricity demand reduction

ABSTRACT

This paper investigates the impact of COVID-19 and the global pandemic on the energy sector dynamics. Hourly electricity demand data was collected and analyzed for the province of Ontario. It is evident that health-related pandemics have a detrimental and direct influence on the concept of the smart city. This is manifested through various social, economic, environmental, technological and energy-related changes. The overall electricity demand of the province for the month of April of this year amidst pandemic conditions declined by 14%, totaling 1267 GW. A unique trend of reciprocating energy demand exists throughout the week. The post-COVID-19 indicates higher energy demand in the earlier part of the week and a lower demand in the latter part of the week. Pre-pandemic, the days of highest electricity demand were in the latter part of the work week (Wed-Fri) in addition to the weekend. Post-pandemic, the highest electricity demand occurred in the earlier part of the week (Mon-Tue). Hourly electricity demand shows a clear curve flattening during the pandemic, especially during peak hours of 7–11 in the morning and 5–7 in the evening, resulting in significant demand reductions during these periods. Lastly, due to COVID-19, GHG emission reductions of 40,000 tonnes of CO_2e were achieved along with savings of $131,844 for the month of April.

1. Introduction

The pandemic of COVID-19 has caused a severe global dilemma and has impacted every aspect of life. In addition to massive loss of life, this pandemic has had economic, social, technological, political, and health impacts. The pandemic has also had an environmental and an energetic influence due to restrictive measures, such as lockdown, shelter in place, or stay at home orders, to contain the pandemic at a local level. As nations of the world incorporated stricter border control and limited international movements, civil aviation bore major economic repercussions. The air transport industry has forecasted a reduction of 861 to 1292 million passengers and approximately USD $151 to $228 billion loss of gross operating revenues of airlines under a V-shaped path, where first signs of recovery are not predicted until late May [1]. The same source projects a 44%-80% decline in international passengers in 2020. The industry supports a total of 65.5 million jobs globally and has been severely impacted by COVID-19 and the halt of all international travel and tourism. From an energy perspective, demand takes on a major role in the transportation than the residential sector [2]. Another significant impact of COVID-19 is the most substantial global equity collapse since the Great Depression, exacerbated by a 60% oil price slump. Social consequences due to COVID-19 include increased aggression in homes due to financial insecurity, stress, and uncertainty. A major digital transformation has occurred due to the pandemic, with virtual business, educational and social platforms emerging quickly. The COVID-19 outbreak affects all segments of the population and is particularly detrimental to members of the most vulnerable social groups. In addition, more than one billion youth are now no longer physically in school after the closure of schools and universities across many jurisdictions [3]. Additionally, the enforcement of social distancing has resulted in mental health impacts. In the United States, the national Disaster Distress Helpline saw a 338% increase in calls in March compared to February 2020 [4]. Worship services of various faiths have been widely cancelled, including the closure of Sunday Schools, as well as the cancellation of pilgrimages surrounding observances and festivals. On the other hand, research shows that while children were motivated to save energy by being given responsibility, parents viewed saving energy more positively when framed as educating their child [5]. This pandemic forced parents and children to unite together at homes for extensive continuous periods of time, which brings the possibility of being energy conscious. The technology sector has witnessed several impacts including reduction in raw material supply, disruption to the electronics value chain and inflationary risk on products. Ventures with remote-working technologies are already

* Corresponding author.
E-mail address: Azzam.aburayash@ontariotechu.net (A. Abu-Rayash).

https://doi.org/10.1016/j.erss.2020.101682
Received 10 June 2020; Received in revised form 19 June 2020; Accepted 24 June 2020
Available online 02 July 2020

seeing increased demand as businesses increase their remote-working capabilities. IT forecasts continued demand for cloud infrastructure services and potential increases in spending on specialized software. Increased demand on telecommunication infrastructure is also anticipated as the culture of working remotely is encouraged [6]. Furthermore, the global uncertainty caused by COVID-19 has inspired further research on the future of technological progress. The Atlantic Council's Geotech Center circulated a questionnaire to more than 100 technology experts to record their expectations of the COVID-19 impact on innovation in five key fields. Results show that the pandemic will accelerate innovation significantly in the future of work, medical and bioengineering as well as trust and supply chain and data and AI [7]. Politically, some countries embodied stewardship in helping each other, while others worried about more individual interests. For example, Turkey aided the suffering Italy and Spain by delivering medical supplies, personal protection equipment and disinfectants [8]. Conversely, the USA utilized the Defense Production Act to end mask exports to Canada and Latin America [9]. Significant political unrest, even among allies, has erupted in response to COVID-19. The global battle against this pandemic with its socioeconomic ramifications reinforces the demand for global action against climate change and the environmental crisis. In fact, the world got to experience first-hand how unpreparedness is catastrophic in times of emergencies. This pandemic has portrayed a vivid impact globally in times of crisis. Environmentally, industrial shutdowns in China estimate CO_2 emission reduction of approximately 25% in February of 2020 compared with the same month in 2019 [10]. The sudden reduction in economic activity globally has resulted in some short-term environmental improvements, including significant reductions in local air pollution and greenhouse gas emissions in many countries, particularly in urban areas. Furthermore, the energy demand has dropped due to the shutdown and cease of various manufacturing and economic sectors. Therefore, the impact of this pandemic will have an ongoing long-term effect on various lifestyle aspects. Thus, it is critical to study those impacts and forecast important parameters from the lessons learned. Fig. 1 shows the timeline of events in March 2020 [11].

This study is aimed at analyzing the impact of the global pandemic on the energy sector, using the province of Ontario as a case study. The novelty of this study revolves around the interconnectedness of the smart city concept to the resiliency of energy and health infrastructures in cities. This paper makes an important contribution to the dialogue on energy by forecasting socioeconomic, behavioral and cultural changes due to this pandemic and their potential impact on the energy sector. The specific objectives of this paper are:

- To develop a novel methodology to characterize smart cities and assess their smart performance based on seven main domains,
- To analyze the daily energy demand for Ontario before and after COVID-19 coronavirus pandemic,
- To analyze the zonal energy demand for Ontario along with demand variations for on-peak and off-peak hours, and
- To conduct an inclusive parametric study, investigating the impact of various critical socioeconomic parameters and surrounding conditions on energy demand.

2. Model development and methodology

Past research was limited to introducing aspects to smart cities and evaluating local and regional projects based on smart city objectives. This research expands on the aspects of a smart city by including critical components such as energy, resources and pandemic resiliency as part of the assessment. These aspects and their consequent indicators are assessed and categorized into five levels of increasing smartness. Fig. 2 shows the proposed progression from the lowest level 1 to the highest achievable level 5. Together, they form the smart city matrix. As cities integrate more smart initiatives, they transition from level 1 to level 5. The aspects considered in the smart city concept for this paper are comprised of seven main sub-indexes. Each aspect constitutes several indicators that can be quantified for further analysis using this methodology. These aspects are described in detail in Fig. 3 and are listed as follows:

- Smart Environment
- Smart Economy
- Smart Society
- Smart Governance
- Smart Energy
- Smart Infrastructure
- Smart Transportation
- Pandemic Resiliency

These sub-indexes and corresponding indicators will be used to assess cities for their smartness. The Smart City Index (SCI) is the metric used to assess cities in their smartness. This index is composed of seven main domains including the smart environment index, smart economy index, smart society index, smart governance index, smart energy index, smart infrastructure index, transportation index and pandemic resiliency. These indexes are further assessed with specific indicators. This comprehensive concept is illustrated further in Fig. 3. The domains and indicators selected are aligned with the UN's SDGs as well as the WCCD. For instance, SDG 1 is no poverty, and for this model, poverty rate is evaluated as a percentage. Furthermore, a smart economy considers the GDP per capita, R&D expenditure, unemployment rate and the Gini coefficient.

Smart governance is assessed based on government effectiveness, digitalization, public participation and the corruption rate within the

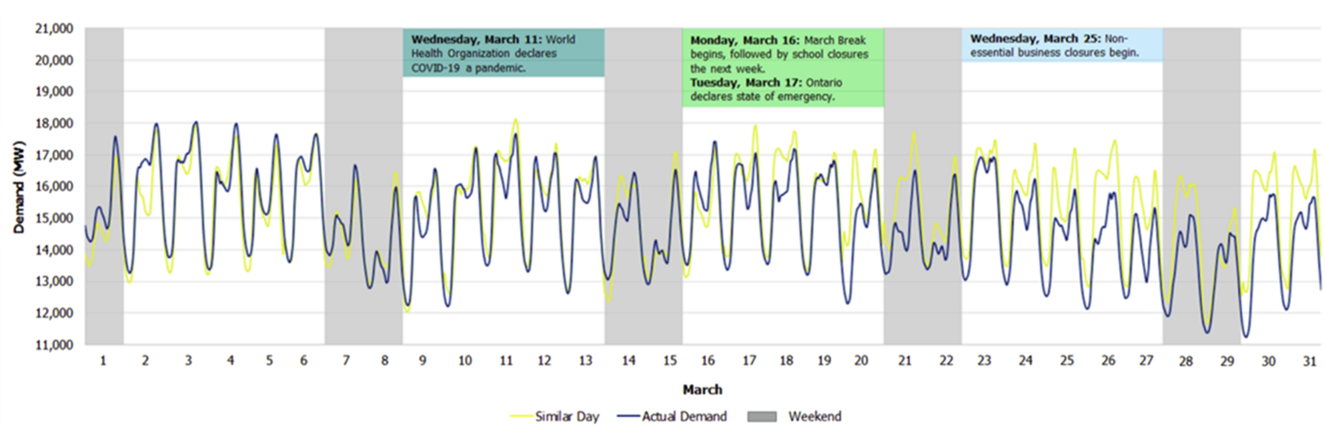

Fig. 1. Impact of COVID-19 on Ontario electricity demand patterns for the month of March (Adopted from: [11]).

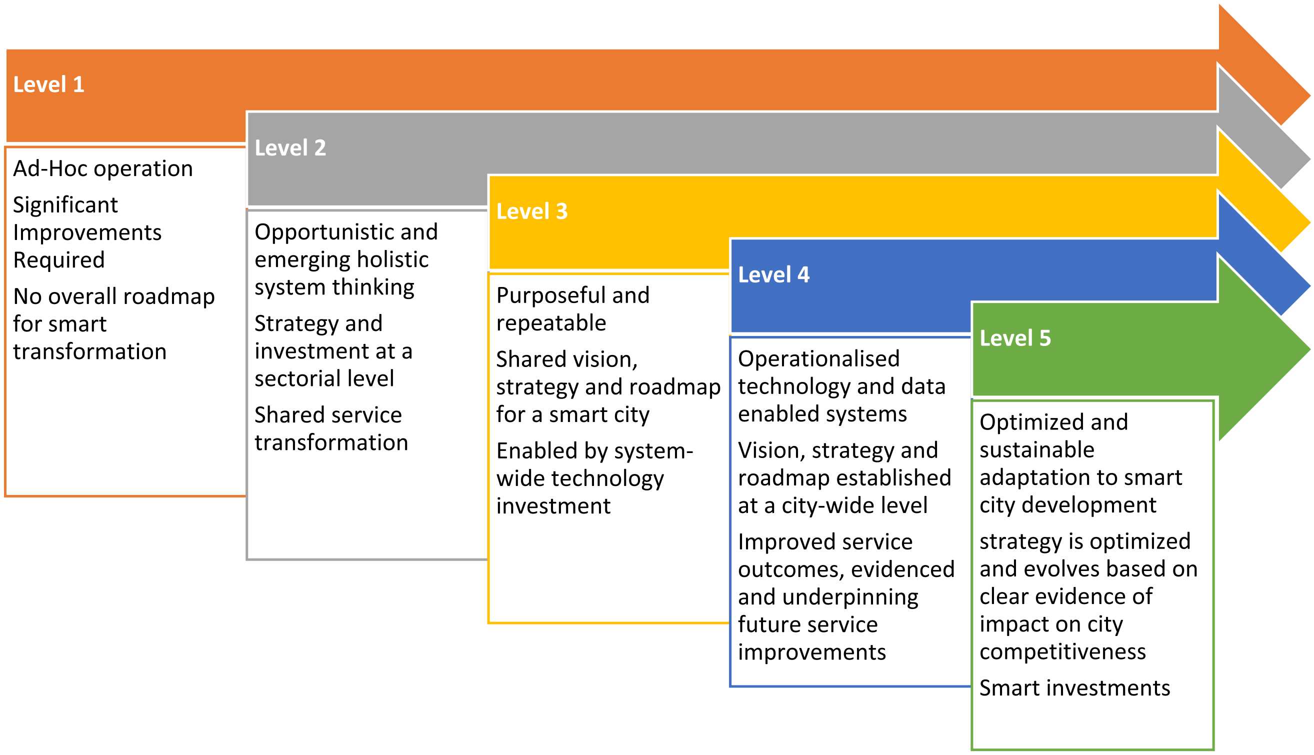

Fig. 2. Levels of increasing smartness for cities.

government. Smart energy takes into consideration the energy efficiency of the systems, utilization of clean energy, energy storage, and the overall cost of energy. As for the rest of the domains, further details about their characterization and assessment are elaborated later in their respective sections.

Furthermore, the economic aspect must be both viable as well as inclusive, allowing for growth and economic prosperity. Smart cities without smart people and high level of innovation, creativity and education is virtually impossible. Moreover, smart cities have laws, bylaws and written policies to ensure the longevity and sustainability of measure that the city takes regardless of political turnover. The energy sector for a smart city must rely on clean, abundant and reliable energy sources coupled with efficient, integrated and multigenerational systems to provide dependable and reliable services.

Also, a smart city is one with efficient mobility and reliable transportation. Lastly, a smart city is one that is resilient in face of pandemics and national catastrophes which target the loss of life. Considering COVID-19, the world has witnessed cities that have managed the outbreak better than other cities. The frailty of the health system worldwide has been exposed clearly. A smart city is one that has an effective response rate to any pandemic or outbreak. In addition, a smart city is one that utilizes all available resources to minimize loss of life and support the well-being of effected citizens economically, socially and mentally. Lastly, a smart city is one that already has a robust infrastructure and health system that will remain steadfast and effective considering any outbreak.

Fig. 4 shows the aspects that have been impacted by the COVID-19 pandemic. In summary, this virus has impacted all aspects of life, including the economy, social life, politics, the environment, technology sector as well as the health sector. The world is undergoing an economic crisis currently while dealing with the pandemic. International trade is virtually on hold until the calamity ends. Health-wise, in addition to the massive death toll worldwide, the rise of mental health problems is concerning. The technological sector is adapting well to the situation through innovation and emerging new technologies to manufacture face masks, ventilators and personal protective equipment in response to demand. Virtual services are also booming amidst market restrictions to essential services. Self-isolation and social distancing have taken a toll on people socially and the lockdown of cities and shutdown of recreational amenities has led to increased mental health cases. Political conflict, even among allies such as Canada and USA over acquisition of basic PPE was observed. The only aspect that benefited is

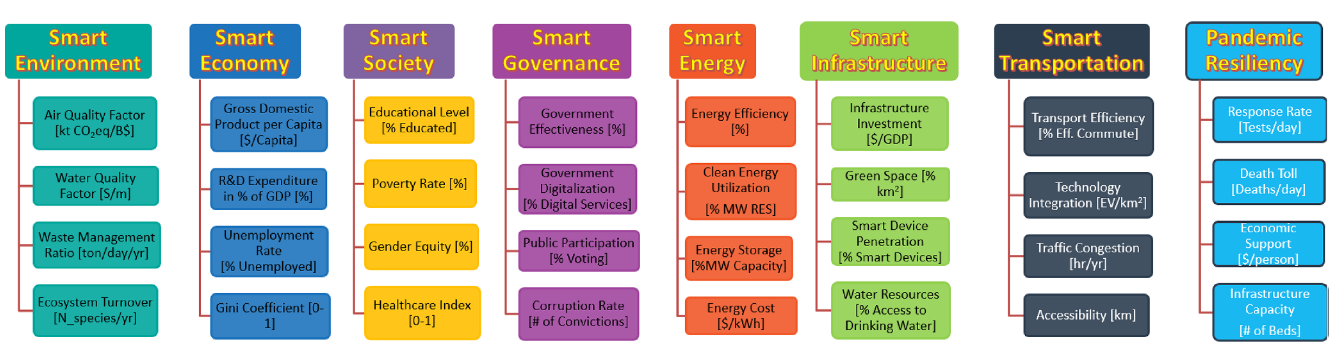

Fig. 3. Aspects of smart cities including main indicators for each sub-index.

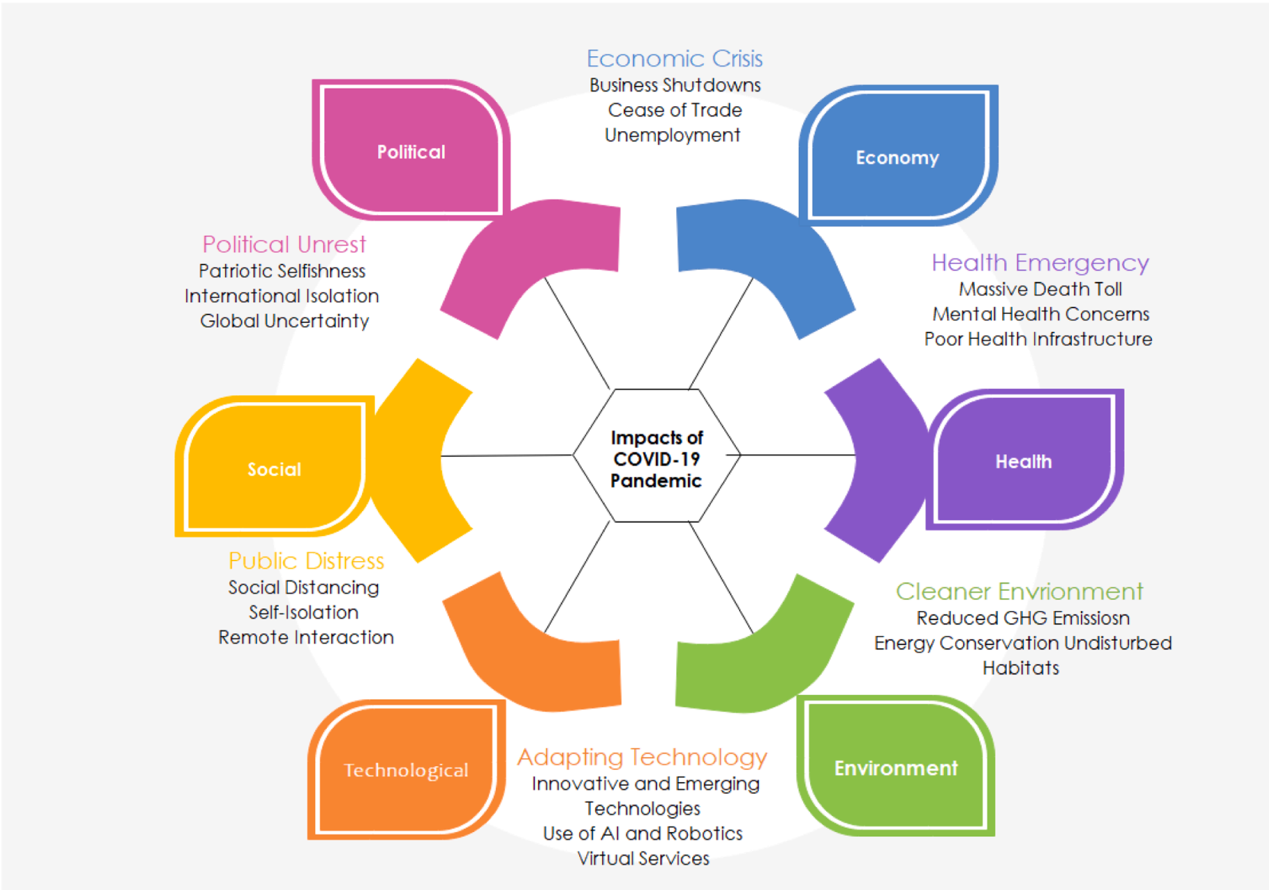

Fig. 4. Impacts of COVID-19 pandemic on different sectors.

the environment as GHG emissions were reduced due to market limitations on mobility.

3. Modeling and analysis

The process of evaluating cities for their smartness needs to be methodically quantified in order to yield reliable information. The indicators were selected based on a logical and methodical approach using statistical methods and mathematical models to reflect each aspect of the smart city, while ensuring simplicity and reliability of the model. Indicators are gauges that enable researchers to summarize, simplify and condense complex dynamic information into meaningful and useful data.

3.1. Smart environment sub-index

This aspect is essential to the concept of smart city as it pertains to the wellbeing of the natural resources universally. Many local emissions and outputs have global and regional impacts. The world is vulnerable to global climate change and this is evident with numerous signs of danger across all continents. In order to assess this aspect of a smart city, the following function is used:

$$\gamma_{SEnv} = \beta_{AQ}{}^{\omega AQ} \times \beta_{WQ}{}^{\omega WQ} \times \beta_{WM}{}^{\omega WM} \times \beta_{ET}{}^{\omega ET}$$

where β represents the dimensionless normalized value for the respective indicator and ω represents the weight associated with each indicator. *AQ*, *WQ*, *WM*, *ET* represents the indicators used for this sub-index in the following order, air quality, water quality, waste management, and turnover rate.

3.2. Smart economy sub-index

In order for any city to be considered smart, it must have prosperous economic activity stemming from effective strategies and an aspiring vision. A smart economy is one that ensures citizens have better opportunities and sufficient revenue to cover their expenses and enahnce their standard of life. This aspect is assessed by evaluating the indicators using the following function:

$$\gamma_{SEco} = \beta_{GDP}{}^{\omega GDP} \times \beta_{RD}{}^{\omega RD} \times \beta_{UR}{}^{\omega UR} \times \beta_{GC}{}^{\omega GC}$$

where γ_{SEco} is the smart economy sub-index, which is evaluated by assessing the GDP β_{GDP}, research and development β_{RD}, unemployment rate β_{UR}, and Gini Coefficient β_{GC}.

3.3. Smart society sub-index

Society is the backbone of every city. In order for the city to be smart, this aspect must also be competitive, creative, innovative and smart. This aspect is evaluated by computing the different indicators in the following function:

$$\gamma_{SSoc} = \beta_{EL}{}^{\omega EL} \times \beta_{PR}{}^{\omega PR} \times \beta_{GEq}{}^{\omega GEq} \times \beta_{HI}{}^{\omega HI}$$

The normalized values for each indicator will be discussed later in the paper for each indicator. These values will also be analyzed and processed further using various aggregation methods and regression analyses. The smart society γ_{SSoc} subindex is evaluated by assessing the educational level β_{EL}, poverty rate β_{PR}, gender equity β_{GEq}, and healthcare index β_{HI}.

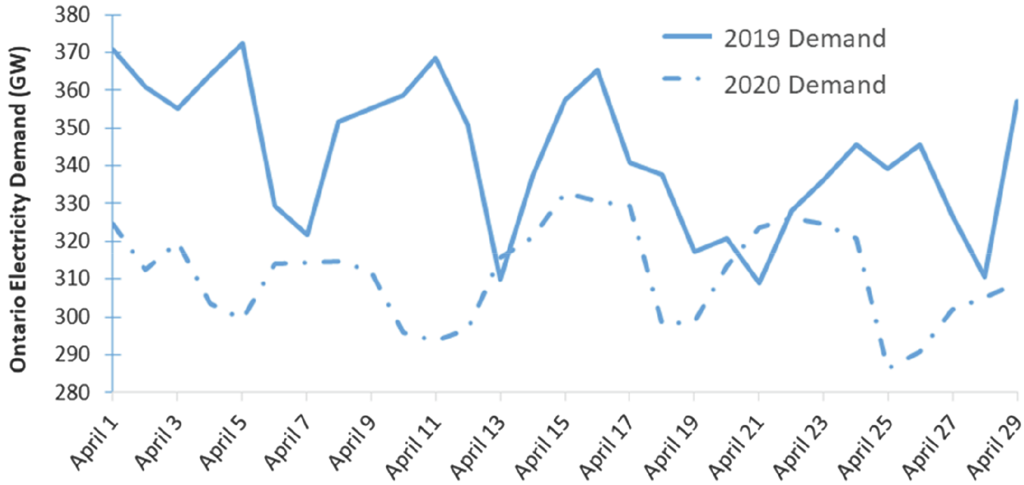

Fig. 5. Comparison of the daily electricity demand for Ontario for the month of April in 2019 and 2020 [Data from: [11]].

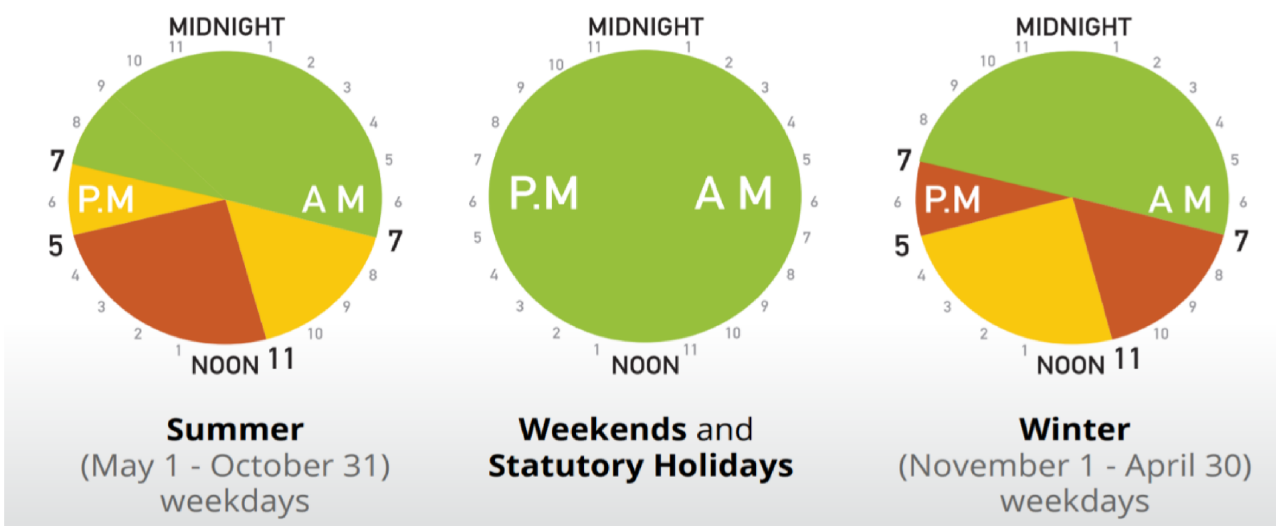

Fig. 6. Chart showing on-peak and off-peak electricity demand in Ontario [Adapted from: [11]].

3.4. Smart governance sub-index

Cities are heavily populated metropolitan areas with municipal level of governance. They are also impacted by regional or upper-tier municipality or even federal policies. Therefore, it is important for this aspect to be included in the assessment to ensure infrastructural improvements, process enhancements and adoption of a shared vision towards a smart city. The main catalyst for smart city transformation is smart governance, which is assessed using the following function:

$$\gamma_{SGov} = \beta_{GE}{}^{\omega GE} \times \beta_{GD}{}^{\omega GD} \times \beta_{PP}{}^{\omega PP} \times \beta_{CR}{}^{\omega PCR}$$

This sub-index is limited to four main indicators that encompass many aspects of smart governance including internal processes, corporate strategy, ICT integration, transparency and structure. This sub-index is evaluated by assessing the government effectiveness β_{GE}, government digitalization β_{GD}, public participation β_{PP}, and corruption rate β_{CR}.

3.5. Smart energy sub-index

This aspect reflects some of the novelty of this research as it has never been considered in any smart city assessment framework. Energy including electricity and gas or other sources of fossil fuels or renewables and alternative sources constitute the lifeline of a city. Without reliable sources, systems and efficient energy services, a city can virtually shut down and become immobile with significant economic and social impacts. This is evaluated as follows:

$$\gamma_{SEn} = \beta_{\eta}{}^{\omega_\eta} \times \beta_{CEU}{}^{\omega CEU} \times \beta_{ESt}{}^{\omega ESt} \times \beta_{EC}{}^{\omega EC}$$

The assessment of this aspect will follow the 3S framework [12,13], and energy will be analyzed from the source, system and service perspectives accordingly. The indicators used to assess this sub-index include the energy efficiency β_η, clean energy utilization β_{CEU}, energy storage β_{ESt}, and energy cost β_{EC}.

3.6. Smart infrastructure sub-index

This aspect is also novel and has not been considered in any assessment. Assessing the resources in a city, especially the essential infrastructure such as water and food to determine the level of smartness of a city, is critical. While the smart environment sub-index focuses on the preservation of natural resources, this sub-index assesses the consumption and reliability of available resources. For example, the model considers if a city relies on importing essential goods or if it is self-sufficient. This aspect is assessed using the following function:

$$\gamma_{SInfr} = \beta_{II}{}^{\omega II} \times \beta_{GS}{}^{\omega GS} \times \beta_{SDP}{}^{\omega SDP} \times \beta_{WR}{}^{\omega WR}$$

Since this aspect is novel to the assessment of the smart cities

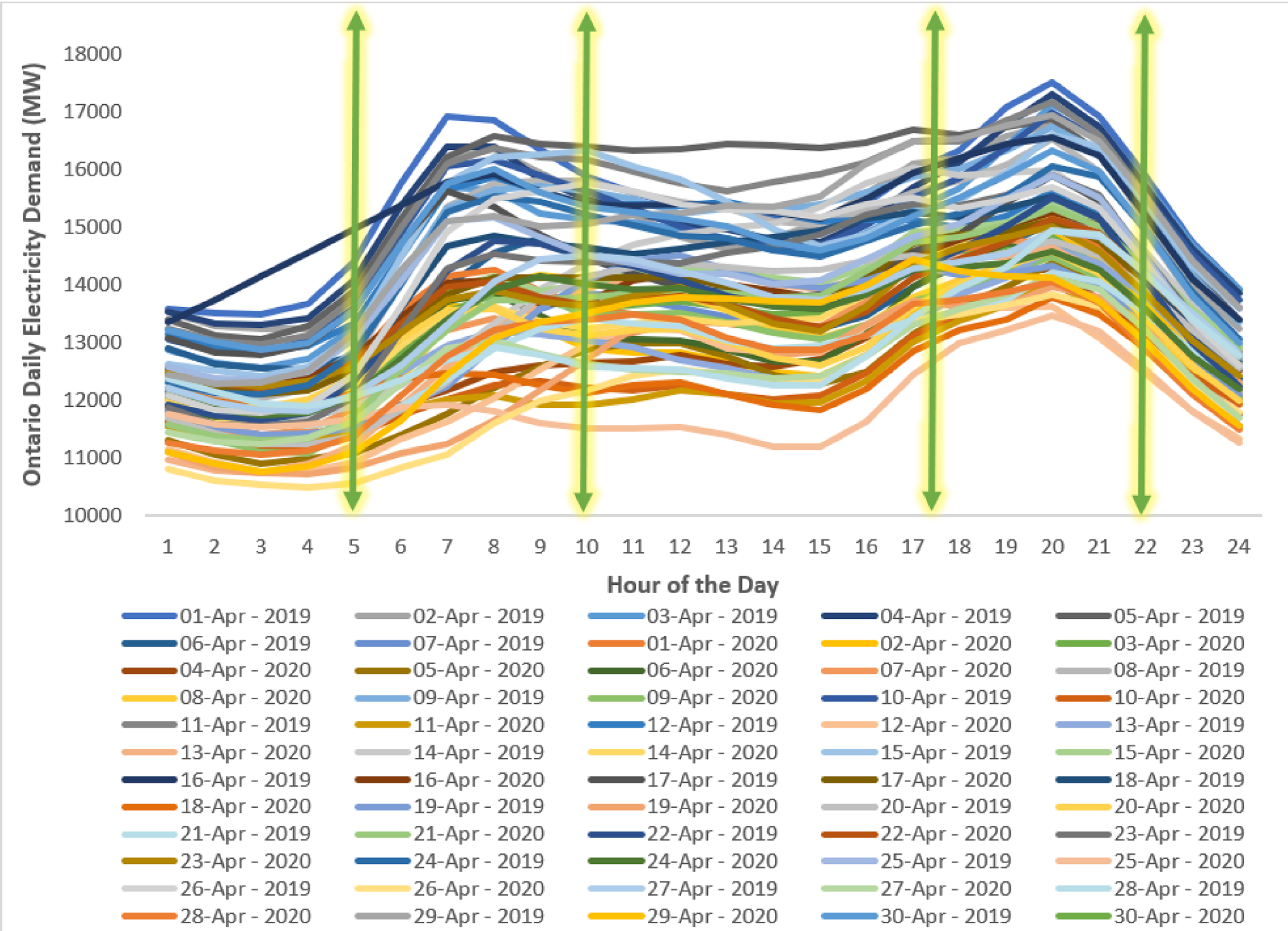

Fig. 7. Hourly electricity demand for the days of April of 2019 and 2020 [Data from: [11]].

framework, its impact will be analyzed and evaluated in depth later in this research. This sub-index Is evaluated by assessing the infrastructure investment β_{II}, green space β_{GS}, smart device penetration β_{SDP}, and water resoruces β_{WR}.

3.7. Smart transportation sub-index

Mobility and transportation is one of the main features of a city. The fact that all services are interconnected and being heavily populated inspired cities to develop various transportation solutions. This includes efficient urban planning and using environmentally benign transportation solutions. This aspect is assessed based on the following function:

$$\gamma_{SMob} = \beta_{TE}{}^{\omega TE} \times \beta_{TI}{}^{\omega TI} \times \beta_{TC}{}^{\omega TC} \times \beta_{AC}{}^{\omega AC}$$

This domain is explored by assessing a number of indicators including transport efficiency, technology integration in the transportation sector, traffic congestion and accessibility. This sub-index is evaluated by assessing the transportation efficiency β_{TE}, technology integration β_{TI}, traffic congestion β_{TC}, and accessibility β_{AC}.

3.8. Pandemic resiliency

Having robust and resilient infrastructure and plans in response to health outbreaks in cities is essential in order to preserve the city's economical, social, political, and environmental competence. This aspect is assessed based on the following function:

$$\gamma_{PResil} = \beta_{RR}{}^{\omega RR} \times \beta_{DT}{}^{\omega DT} \times \beta_{ES}{}^{\omega ES} \times \beta_{IC}{}^{\omega IC}$$

This domain is explored by assessing a number of indicators including the response rate to the pandemic, death toll, economic support to residents of the city, and the infrastructure capacity to accommodate pandemic-related patients along with other patients. This unique sub-index is evaluated by assessing the government's response rate β_{RR}, death toll β_{DT}, economic support β_{ES}, and infrastructure capacity β_{IC}.

4. Results and discussion

Comprehensive hourly energy demand data was analyzed to better understand the dynamic changes to the energy sector due to COVID-19. Once again, for the purpose of this study, energy data is limited to electricity only due to the availability and readiness of data. It is assumed that energy data pertaining to heating is approximately equivalent to the electric load. For the purpose of this study, data for the month of April of 2020 has been compared to data of April of 2019. The months represent the monthly period under COVID-19 impact and the period without any COVID-19 impact. In Ontario, school shutdown was enforced on March 13th. A few days later, the government of Ontario declared a state of emergency, closing bars, restaurants, libraries, cinemas and all public gatherings. All non-essential businesses along with a province-wide closure of all outdoor recreational amenities commenced March 30th. Overall, the electric demand for the province of Ontario was reduced notably, specifically the overall daily demand as well as the demand during specific on-peak hours. In fact, flattening of the demand curve is observed for Ontario. Fig. 5 illustrates the total daily electricity demand in Ontario for the month April. It compares the demand fluctuation for this month between 2019 and

Table 1
Daily electricity demand for Ontario for the month of April pre and post COVID-19 pandemic [Data from: [11]].

Date	Total Ontario Demand 2019 (GW)	Total Ontario Demand 2020 (GW)	Percent Reduction (%)
April 1	370.908	324.704	14%
April 2	360.908	312.584	15%
April 3	355.017	319.699	11%
April 4	364.127	303.443	20%
April 5	372.227	299.548	24%
April 6	329.292	313.982	5%
April 7	321.689	314.437	2%
April 8	351.624	314.813	12%
April 9	355.249	312.269	14%
April 10	358.802	296.047	21%
April 11	368.527	293.731	25%
April 12	350.856	296.847	18%
April 13	309.92	315.556	−2%
April 14	337.247	320.943	5%
April 15	357.414	332.951	7%
April 16	365.237	330.564	10%
April 17	340.84	329.292	4%
April 18	337.757	298.009	13%
April 19	317.14	298.905	6%
April 20	320.753	313.503	2%
April 21	308.947	323.573	−5%
April 22	328.186	326.146	1%
April 23	336.298	324.675	4%
April 24	345.447	320.885	8%
April 25	339.238	286.468	18%
April 26	345.6	290.868	19%
April 27	326.784	301.906	8%
April 28	310.646	305.269	2%
April 29	357.199	309.017	16%

2020, given the COVID-19 pandemic situation.

The trendlines show several findings, summarized below:

- Monthly electricity demand was reduced by a total of 14%, which translates to 1267 GW.
- Greatest daily demand reductions were observed on weekends, with an average of 18% daily reductions and a highest reduction of 25%.
- Provincial electricity demand in 2020 exceeded that of 2019 by 2–5% on two occurrences, both of which were weekdays
- Period of April 19th to April 25th highlights the week of the highest COVID-19 deaths in Ontario. It is interesting to observe that the electricity demand for that week in 2020 was increasing steadily day by day, whereas it was stable and declining in 2019.
- The demand dips were sharper and more instant in 2019, whereas they were parabolic and curvy in 2020.
- In 2019, the demand would increase throughout the week and reach a peak on the weekend. The demand in 2020 would reach a peak by mid-week and decline through the rest of the week including the weekends.

This is due to the shutdown of recreational and social establishments across the province. Weekends of 2019 as illustrated show increased electricity demand on weekends, relative to weekdays. However, 2020 weekends portray the opposite relationship with lower electricity demand on weekends than on weekdays. The occurrences were on a Monday and a Tuesday, both of which consistently record the lowest degree of change. Mondays and Tuesdays are the beginning of the work week and it is hypothesized that workers are engaged remotely from home with a higher workload than the remainder of the weekdays. Pre-pandemic, Mondays are Tuesdays observed lower electricity demand than the rest of the week. However, post-pandemic, these two days show the highest demand throughout the week.

This demonstrates significant lifestyle changes due to the pandemic. The electricity demand footprint in the latter part of the week, including the weekend declined considerably. Pre-pandemic, the days of highest electricity demand were in the latter part of the week (Wed-Fri) in addition to the weekend. Post-pandemic, the days of highest electricity demand shift from the latter part of the week to the earlier part of the week (Mon-Tues). According to the IESO, hours between 7 and 11 in the morning as well as hours between 5 and 7 in the evening are the hours of peak energy demand for the winter months including April. Fig. 6 shows the variation in peak and normal energy demand for hours throughout the day.

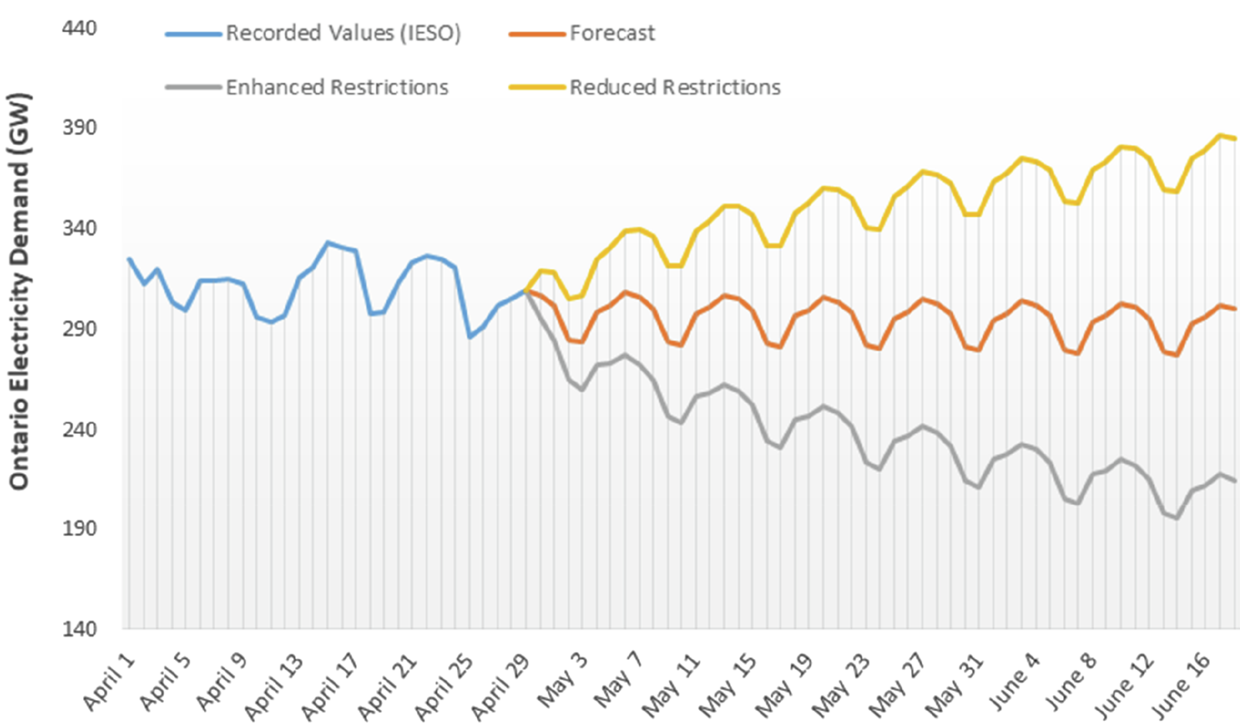

Fig. 8. Daily electricity demand forecast for the months of May and June [Data from: [11]].

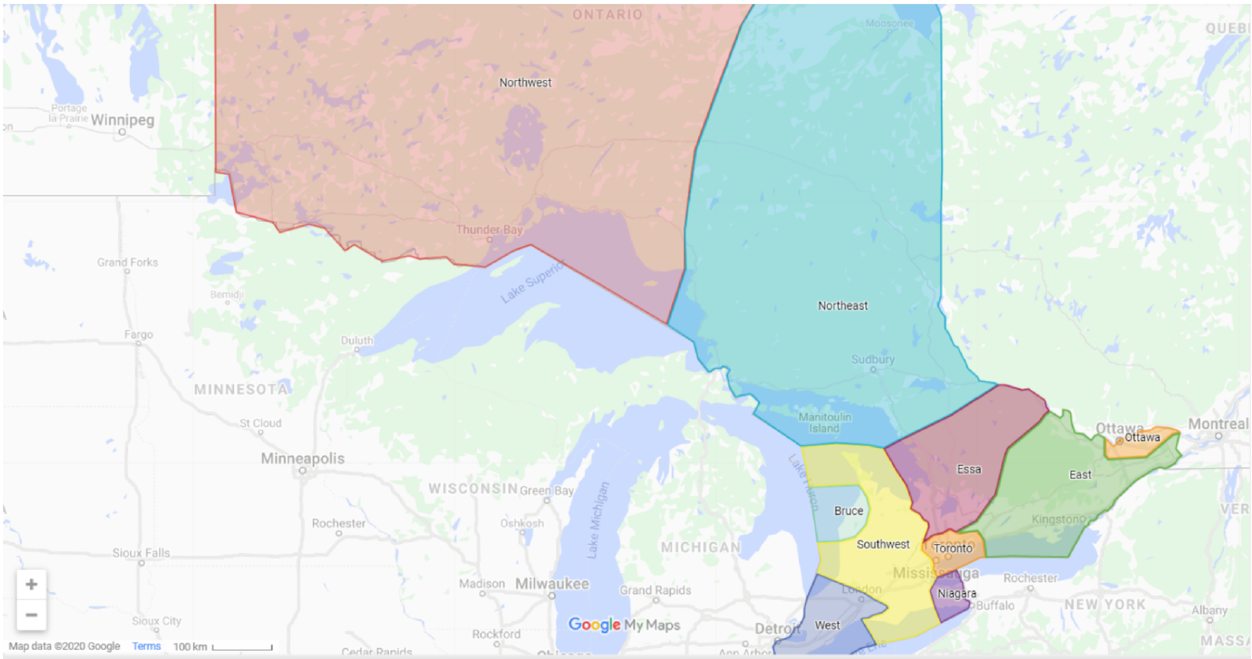

Fig. 9. IESO zonal map for electricity demand [Data from: [11]].

Table 2
Hourly electricity demand reduction for all zones due to COVID-19 [Data from: [11]].

Hour	Toronto Zone	Southwest Zone	West Zone	Northwest Zone	Northeast Zone	Ottawa Zone	East Zone	Essa Zone	Niagara Zone	Bruce Zone
1	-8%	-18%	-6%	-2%	-14%	-14%	-11%	-8%	-12%	-54%
2	-8%	-18%	-6%	-3%	-14%	-14%	-11%	-7%	-13%	-54%
3	-9%	-18%	-6%	-4%	-14%	-14%	-12%	-8%	-13%	-54%
4	-9%	-18%	-6%	-3%	-13%	-14%	-12%	-8%	-14%	-47%
5	-11%	-19%	-8%	-2%	-12%	-16%	-14%	-9%	-15%	-46%
6	-15%	-21%	-9%	-3%	-13%	-20%	-17%	-12%	-16%	-37%
7	-18%	-22%	-9%	-5%	-15%	-23%	-21%	-15%	-20%	-34%
8	-17%	-22%	-10%	-6%	-16%	-22%	-25%	-15%	-20%	-32%
9	-17%	-21%	-12%	-5%	-16%	-21%	-28%	-14%	-19%	-32%
10	-16%	-20%	-14%	-6%	-16%	-19%	-27%	-14%	-19%	-36%
11	-15%	-19%	-13%	-5%	-16%	-17%	-22%	-12%	-17%	-37%
12	-13%	-18%	-13%	-5%	-14%	-14%	-20%	-10%	-17%	-39%
13	-13%	-19%	-12%	-5%	-14%	-15%	-22%	-12%	-18%	-37%
14	-14%	-20%	-12%	-5%	-15%	-16%	-21%	-12%	-17%	-38%
15	-14%	-20%	-12%	-4%	-16%	-17%	-24%	-12%	-18%	-38%
16	-14%	-19%	-10%	-5%	-15%	-17%	-23%	-11%	-17%	-33%
17	-12%	-16%	-8%	-2%	-14%	-15%	-17%	-8%	-14%	-33%
18	-11%	-17%	-8%	-1%	-13%	-14%	-14%	-8%	-14%	-44%
19	-12%	-18%	-8%	-2%	-14%	-15%	-14%	-9%	-15%	-48%
20	-12%	-19%	-10%	-3%	-15%	-16%	-15%	-11%	-16%	-49%
21	-12%	-19%	-11%	-4%	-15%	-17%	-15%	-11%	-16%	-50%
22	-11%	-18%	-10%	-3%	-15%	-15%	-14%	-10%	-14%	-49%
23	-10%	-18%	-9%	-3%	-15%	-14%	-12%	-8%	-14%	-49%
24	-9%	-17%	-7%	-2%	-14%	-13%	-12%	-8%	-12%	-49%
Grand Total	**-13%**	**-19%**	**-10%**	**-4%**	**-14%**	**-16%**	**-17%**	**-11%**	**-16%**	**-42%**

Furthermore, the flattening of the energy demand curve is evident in Fig. 7. The blue and grey shades are the days of April of 2019, while the yellow and orange shades show the days of April of 2020. The flattening of the energy demand curve is clear during peak hours. A significant reduction in off-peak hours is also observed.

The Ontario daily electricity demand in April of 2019 fluctuated between 12 GW and 17 GW per hour. COVID-19 circumstances caused significant shutdowns, resulting in substantial energy demand reductions, fluctuating between 10 GW and 14 GW per hour. The lines indicate the hours, in which the curve effect takes place. Table 1 shows the daily demand for the month of April for Ontario pre and post COVID-19.

The greatest reductions occurred on the weekends because these days were the most energy-intensive of 2019. They transformed to the least energy-intensive in 2020, however, due to the pandemic. These days include April 4, 5, 11, 12, 18, 25 and 26. There are also two instances where the 2020 demand exceeded the 2019 demand, notably on April 13 and 21, a Monday and Tuesday, respectively. Using this recorded data from the IESO, electricity demand forecast for the month of May and June has been formulated under the accuracy of 90% confidence. Fig. 8 shows the results of the forecast analysis until June 18, 2020. The model uses actual recorded values from the month of April

Table 3
Cost end environmental analysis of 2019 and 2020 electricity [Data from: [17]].

Date	2019 Electricity Cost	2020 Electricity Cost	2019 GHG Emissions (tCO_2e)	2020 GHG Emissions (tCO_2e)
April 1	$ 51,189	$ 44,646	16,246	14,222
April 2	$ 49,885	$ 42,825	15,808	13,691
April 3	$ 48,892	$ 44,078	15,550	14,003
April 4	$ 50,168	$ 41,568	15,949	13,291
April 5	$ 51,685	$ 41,056	16,304	13,120
April 6	$ 45,395	$ 43,177	14,423	13,752
April 7	$ 44,202	$ 43,273	14,090	13,772
April 8	$ 48,853	$ 43,594	15,401	13,789
April 9	$ 49,218	$ 43,145	15,560	13,677
April 10	$ 49,556	$ 40,457	15,716	12,967
April 11	$ 51,049	$ 40,083	16,141	12,865
April 12	$ 48,681	$ 40,935	15,367	13,002
April 13	$ 42,417	$ 43,703	13,574	13,821
April 14	$ 46,440	$ 44,044	14,771	14,057
April 15	$ 49,627	$ 45,795	15,655	14,583
April 16	$ 50,257	$ 45,392	15,997	14,479
April 17	$ 46,955	$ 45,363	14,929	14,423
April 18	$ 46,807	$ 40,664	14,794	13,053
April 19	$ 43,818	$ 40,999	13,891	13,092
April 20	$ 44,278	$ 43,045	14,049	13,731
April 21	$ 42,429	$ 44,569	13,532	14,172
April 22	$ 45,402	$ 44,772	14,375	14,285
April 23	$ 46,500	$ 44,613	14,730	14,221
April 24	$ 47,850	$ 44,321	15,131	14,055
April 25	$ 46,823	$ 38,968	14,859	12,547
April 26	$ 48,149	$ 39,845	15,137	12,740
April 27	$ 45,111	$ 41,447	14,313	13,223
April 28	$ 42,297	$ 42,196	13,606	13,371
April 29	$ 49,276	$ 42,797	15,645	13,535
Total	**$ 1,373,212**	**$ 1,241,369**	**435,542**	**395,542**

2020 for short-term load forecasting. Since the forecast is limited to June 2020, this range can be acceptable. Climate and weather data for Toronto have also been taken into consideration in this forecasting. The limitation of this forecasting is that it does not take into consideration full re-opening of the economy and industry at once.

The forecast shows a steady decline in the daily electricity demand throughout the summer months. Enhanced restrictions due to COVID-19 can drive down the electricity demand to 190 GW per day. However, reopening of the economy and the market will drive the demand upwards to approximately 400 GW. The average forecasted daily electricity demand revolves around 311 GW, while the loosened restrictions scenario highlights an average daily electricity demand of 350 GW. Loosened restrictions would include measures that the government takes to reopen the economy and re-integrate the society to the post COVID-19 era. According to the IESO, there are 10 zones within the Ontario jurisdiction, as illustrated in Fig. 9. The Toronto zone also includes the Greater Toronto Area and surrounding municipalities. Other segmented zones include the Niagara region, Ottawa and Bruce, which also houses the Bruce Ontario Power Generation nuclear station.

For each zone, the electricity demand for the month of April was analyzed for 2019 and 2020. For this analysis, the hourly demand data was compiled to investigate the hours of greater change as well as the zones of greater impact. Table 2 shows a heat map of the percentage reduction in electricity demand per hour for each zone (see Table 3).

The Bruce zone highlights the greatest reduction rate of 42%, which translates to an average of 881 GW. This zone also portrays a unique reduction schedule, with the off-peak hours being the most effected, which can be attributed to the nuclear powerplant which follows an energy production schedule, reciprocal to the normal energy demand in the other zones. The red cells represent the hours that observed the greatest demand reduction. These hours also happen to be the peak demand hours as discussed earlier. The top three zones that account for most of the electricity demand include Toronto, Southwest and West zones. Fig. 10 shows the hourly electricity demand for these top zones.

Besides the evident curve flattening of the dotted lines as opposed to the solid lines, which denote the hourly electricity demand for each zone, the reduction in the Toronto zone demand is the greatest. The Toronto zonal demand reduction fluctuated between 8% and 17% with a total average of 13% reduction in hourly electricity demand. The dynamics for the remainder zonal demands is highlighted in Fig. 11. The Northeast and Ottawa zones have the greatest demand reductions in that grouping. The Bruce, Northwest and Niagara zones all had minimal demand reductions due to COVID-19. The flat curve of the Bruce zone is attributed to the balancing in energy procurement and storage due to the presence of the nuclear power plant. Furthermore, the East zone has a notable demand depression in mid-day, which is off-peak. Overall, reductions in hourly demand throughout the province is evident and is directly attributed to COVID-19 and the measures taken by the province to limit the spread of the virus.

Fig. 12 shows the electricity demand of the Toronto zone for the month of April for the peak demand hours of the day, namely hours 7–11. As discussed earlier, these hours show the greatest reduction in electricity demand between 2020 and 2019 as illustrated by Fig. 7. These hours are considered the rush hours in Toronto, in which residents start their workdays with intensive electricity consumption simultaneously before the demand curve approaches plateau for the remainder of the day. Major electricity demand between these hours is allocated to extensive use of home appliances, electric-based public transit, and extensive use of office and industry equipment at the start

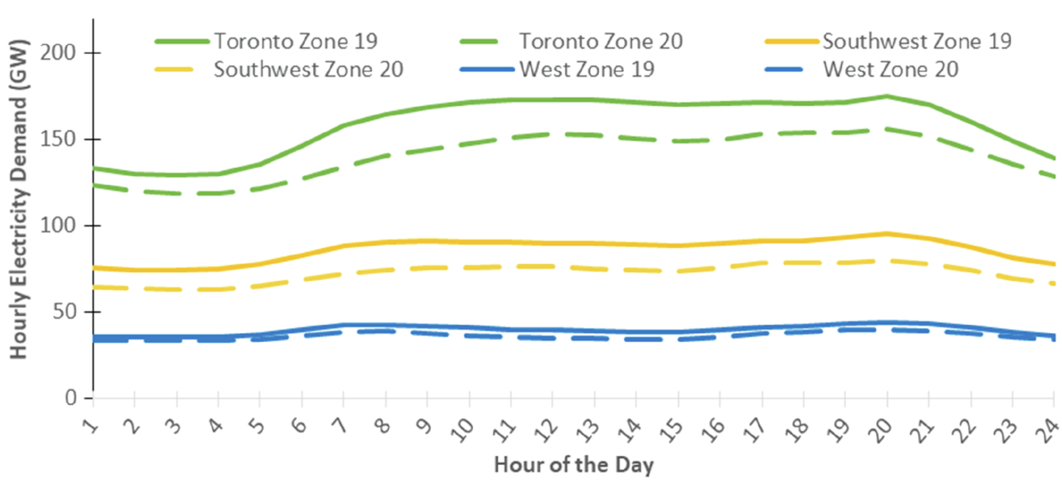

Fig. 10. Hourly electricity demand for the top three zones [Data from: [11]].

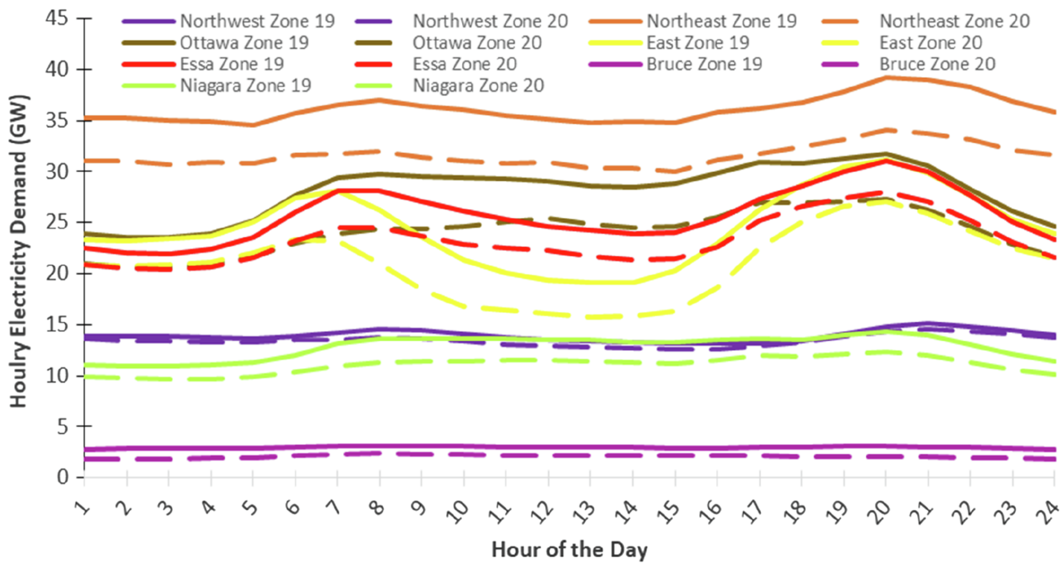

Fig. 11. Hourly electricity demand for the remainder Ontario zones [Data from: [14]].

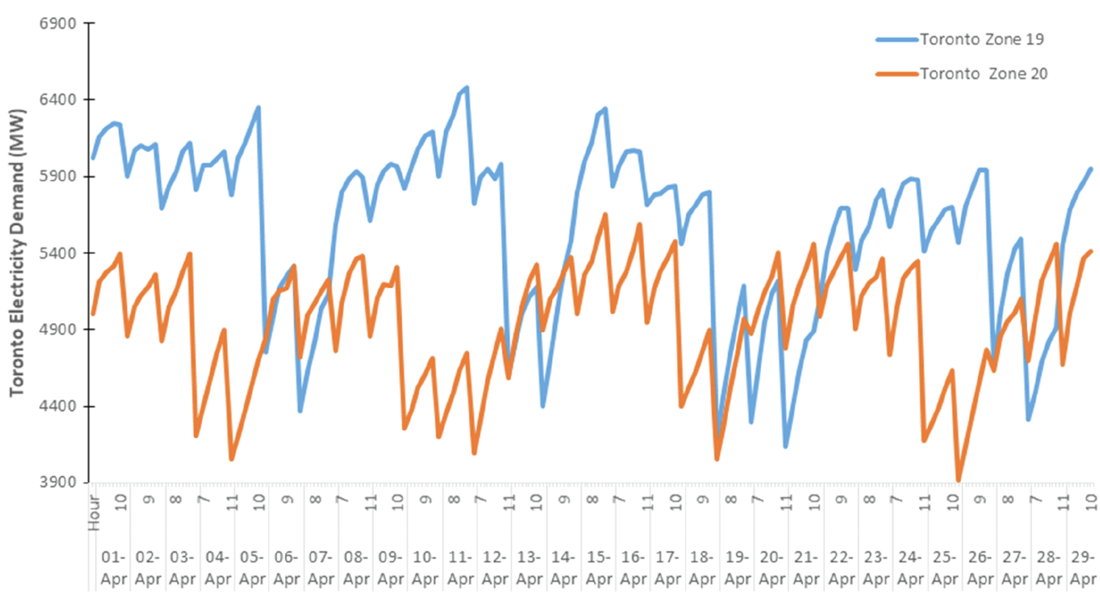

Fig. 12. Peak demand hours for the Toronto zone for April of 2019 and 2020 [Data from: [11]].

of the day. There are notable variations between the 2019 and 2020 trend lines, which can be summarized as follows:

- Considerable demand reduction due to decreased electricity consumption and shut down of all non-essential services and infrastructure
- Variations in steepness of the demand trend lines and rates of change

In 2019, electricity demand fluctuated between 4100 MW and 6500 MW. In 2020, electricity demand fluctuated between 3900 MW and 6500 MW. In 2019, most of the demand increase occurred in the first 2 h, representing a rushed and more rapid speed. The following hours highlight almost no change. In 2020, there is a consistent 4% demand increase within the first hour, followed by a steady 1–2% demand increase throughout the rest of the peak hours.

The hourly demand for electricity for the first 10 days of April is illustrated in Fig. 13. The 2019 baseline is much higher than the 2020 baseline. The increases through the day are also limited and capped for the 2020 baseline. Due to the flattened curve of electricity performance, especially in peak hours, savings of $131,844 was accumulated during the month of April only. This translates to an average of $4,546 savings per day. These results and their economic impacts are consistent with [15] who quantified the effectiveness of energy demand reduction. They concluded that the effectiveness of a reduction in energy demand service is higher in the building sector. In addition, a 25% reduction in energy service demand would be equivalent to 1% of GDP in 2050. Furthermore, the GHG emissions from the electricity demand and consumption is relatively low, compared to international standards. This is due to Ontario's competitive and green grid. In Ontario, the majority of the base load of electricity comes from hydro power and nuclear power sources, both that have minimal environmental footprint. For this study, the 2017 greenhouse gas coefficient ratio was adopted to evaluate the GHG emissions.

This ratio is evaluated at 43.8 gCO_2e per kWh. Therefore, the GHG emission savings for the month of April is approximately 40,000 tonnes of CO_2e. If this rate continued in Ontario for one year, it would achieve 17% of Ontario's emission reduction target defined in the Paris

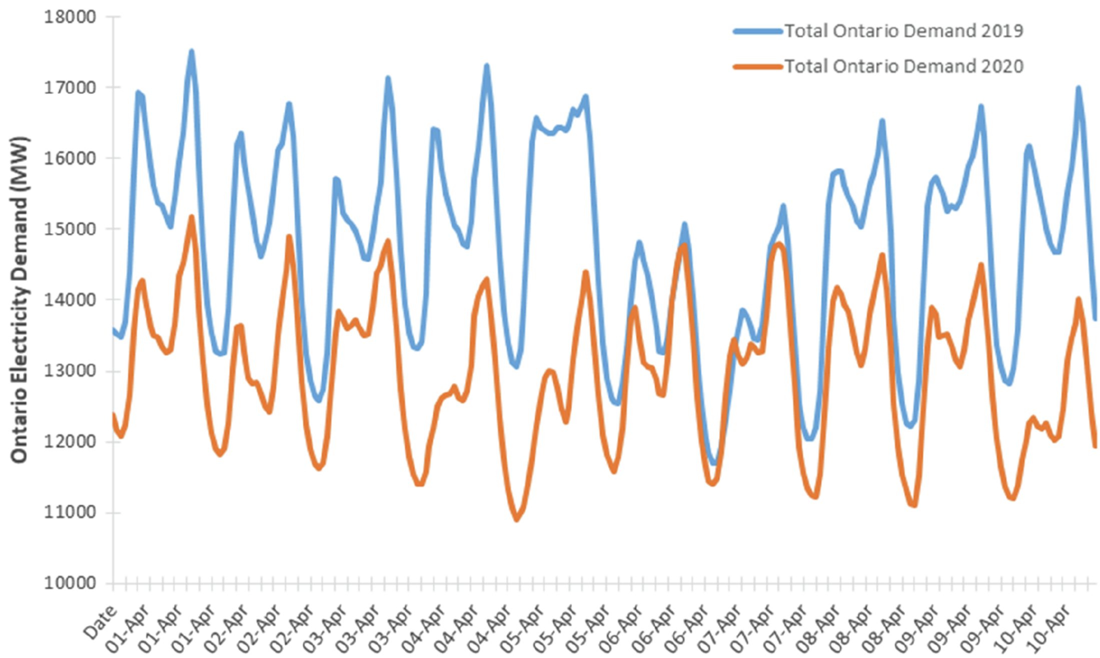

Fig. 13. Hourly electricity demand for Ontario for the first 10 days of April [Data from: [11]].

Agreement. In fact, Ontario's emission reduction target for 2030 is 143 Mt CO_2e, which is equivalent to a 30% reduction from the 2005 baseline [16].

5. Conclusion and policy implications

In conclusion, a unique trend of reciprocating energy demand is evident throughout the week. Post-COVID indicated higher energy demand in the earlier part of the week and a lower demand in the latter part of the week. Previously, energy demand would increase steadily throughout the week and ramp up on the weekend. This is no longer the case after the pandemic. In addition, significant demand reduction is observed for the month of April. In fact, the demand has declined by 14%, which totals to 1267 GW. Greatest daily demand reductions were observed on weekends, with an average of 18% daily reductions and a highest reduction of 25%. GHG emissions were reduced by 40,000 tonnes of CO_2e and savings of $131,844 were realized for the month of April. This analysis of demand trend changes due to the coronavirus pandemic helps us formulate major changes in cultures, habits, lifestyle options and choices in the short-term and long-term future. These fluctuations interconnect with significant energy savings that can be summarized as follows:

- Restricted international travel and limitation to the transportation sector is expected, which will reinforce more energy savings and lower GHG emissions significantly.
- Working remotely will be another cultural and habitual change that will be witnessed throughout industries in order to limit any future disease contraction and to respect future policies and directions around social distancing. This will also influence the energy consumption trend throughout the week by transferring energy demand peaks to earlier parts of the week.
- Self-sufficiency of manufacturing capabilities will also be highlighted to avoid reliance on foreign goods, especially for basic needs and essential commodities.
- The concept of universal basic income will be explored further to avoid economic depression.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] International Civil Aviation Organization (ICAO), "Effects of Novel Coronavirus (COVID-19) on Civil Aviation: Economic Impact Analysis," Montreal, 2020.
[2] F. Kesicki, G. Anandarajah, The role of energy-service demand reduction in global climate change mitigation: Combining energy modelling and decomposition analysis, Energy Policy 39 (11) (2011) 7224–7233.
[3] [3] UN, "Everyone Included: Social Impact of COVID-19," 2020. [Online]. Available: https://www.un.org/development/desa/dspd/everyone-included-covid-19.html.
[4] [4] Amanda Jackson, "A crisis mental-health hotline has seen an 891% spike in calls," CNN, 10-Apr-2020.
[5] M.J. Fell, L.F. Chiu, Children, parents and home energy use: Exploring motivations and limits to energy demand reduction, Energy Policy 65 (2014) 351–358.
[6] P. Sallomi, "Understanding COVID-19's impact on the technology sector," 2020.
[7] Stewart Scott, "COVID-19's potential impact on global technology and data innovation," 2020.
[8] [8] NATO, "Coronavirus response: Turkish medical aid arrives in Spain and Italy," NATO, 01-Apr-2020.
[9] [9] BBC, "Coronavirus: US 'wants 3M to end mask exports to Canada and Latin America,'" BBC, 03-Apr-2020.
[10] Angel Gurría, "An inclusive, green recovery is possible: The time to act is now," 2020.
[11] [11] IESO, "Hourly Demand Report," 2020.
[12] I. Dincer, Greenization, Int. J. Energy Res. 40 (15) (2016) 2035–2037.
[13] I. Dincer, Smart energy solutions, Int. J. Energy Res. 40 (13) (2016) 1741–1742.
[14] IESO, "Hourly Zonal Demand Report," 2020.
[15] S. Fujimori, M. Kainuma, T. Masui, T. Hasegawa, H. Dai, The effectiveness of energy service demand reduction: A scenario analysis of global climate change mitigation, Energy Policy 75 (2014) 379–391.
[16] M. of the Environment and C. and Parks, "Preserving and Protecting our Environment for Future Generations," Toronto, 2018.
[17] IESO, "Ontario Zonal Demand Forecast Report," 2020.