Calgary's municipal buildings energy consumption analysis and forecast

Marcelo Guarido, David J. Emery, Daniel O. Trad, and Kristopher Innanen

ABSTRACT

CO_2 emissions are pointed to as the main cause of Global Warming, and countries around the world are working to reduce their domestic emissions. Canada set to get to zeronet emissions by 2050 and is taking action on different fronts. Although the emissions per capita are reducing, the absolute emissions of the country are still increasing over the years. As part of the country's efforts, the Government of Calgary has set the same goal. We analyzed the Calgary corporate buildings data, which contains energy consumption from different types of municipal facilities and pointed that the overall electricity consumption in the city is declining, while natural gas consumption seems to be following an opposite trend. As a decision-making tool, forecasting models can predict what will be the future energy consumption. However, for that, more complete data is required, containing not only the energy consumption of each building but as well structural information about the same. We performed forecasting of global electricity and natural gas consumption using three different models: SARIMA + XGBoost, Facebook Prophet, and MARS. The first one showed to behave better with the seasonality and outliers, predicting a steady reduction of electricity consumption for the next three years, while the natural gas consumption will, if no action is taken, continue at the same level. Lastly, we did the impact analysis of the reduction of electricity consumption of the Calgary streetlights since 2016, due to an action of the Government of Calgary to change the light bulbs to more energy-efficient ones and estimated that the savings are feeding the equivalent of more than 5000 houses in Alberta.

INTRODUCTION

Global warming is strictly correlated with *Greenhouse Gas Emissions*, and countries need to take action to reduce such waste release to the atmosphere. According to the **Emissions Gap Report 2021** (UNEP and UNEP-DTU, 2021) from the *United Nations Environmental Programme* (UNEP), if all the countries continue their current climate commitments, global temperature will rise at least 2.7°C by the end of the century. To achieve the $1.5°$C goal of the Paris Agreement, emissions need to be cut in half in the next eight years, a reduction in 28 gigatonnes of CO_2 ($GtCO_2$) equivalent in annual emissions. To reach a 2°C target, a drop of 13 $GtCO_2$ in annual emissions is needed by 2030. Buis (2019) shows that at $1.5°$C warming, around 14% of Earth's population will be regularly exposed to severe heatwaves, and the this number jumps to 37% if warming is at 2°C. Adding this to other catastrophic effects such as droughts, wild fires, decrease in availability of drinkable water, increase on extreme precipitations in some areas (Western Canada included), impacts on biodiversity and ecosystems, and ocean impacts (sea level rise, marine ecosystems, acidity, and oxygen levels), we need to take actions on different levels to mitigate global warming effects.

Canada has committed to reduce GHG emission by 40-45% below 2005 levels by 2030, and to moving to net-zero emissions by 2050 (Canada, 2020a). For this goal, the Government of Canada is investing on different fronts: improve energy efficiency in homes and buildings, changing to electric transportation by 2040, taxing emissions and improving energy efficiency of the industrial structures, reducing oil and gas methane emissions to 40-45% by 2025, investing on renewable energy generation, and methane and CO_2 capture. Macquet et al. (2019) and Lawton et al. (2019) show the possibility and importance of injecting captured CO_2 into old oil and gas reservoir, and this technology can be implemented to any "stationary" GHG emitter, such as industrial complexes. However, more is still needed and we need to be clear where to focus.

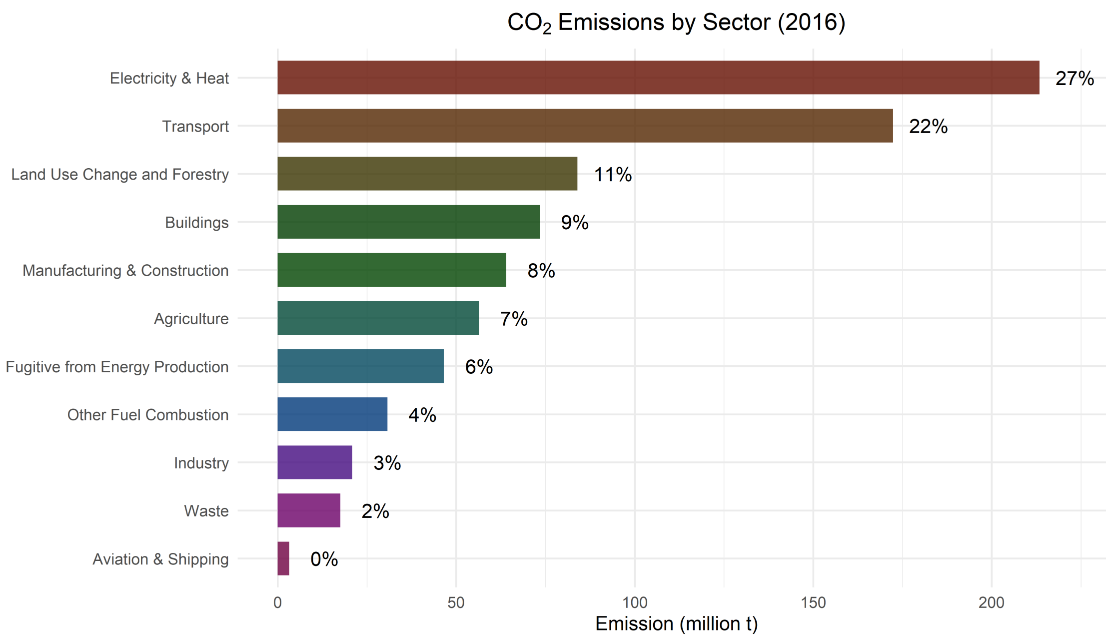

FIG. 1. Canada's CO_2 emissions by sector in 2016.

Our World in Data (Ritchie and Roser, 2020) gathered different datasets, including worldwide GHG emissions. Figure 1 shows how the CO_2 emission is distributed into Canada's economic sectors in 2016: *Electricity & Heat* and *Transportation* are the two largest emitters in Canada, and the first one is the focus of this project. Electricity and heat need an optimization effort: how can we maintain the same output and reduce the energy consumption? One action would be improving buildings heat efficiency, as well understanding the constructions characteristics and how to optimize electricity usage. Part of the decisions lays on the consumption forecasting. Bourdeau et al. (2019) and Wei et al. (2019) make a compilation of conventional (such as ARIMA and MARS) and machine learning (gradient boosting, deep learning) models for energy consumption forecasting. Somu et al. (2021) use a combination of clustering and deep learning algorithms to forecast energy consumption of a four store building in Bombay, India. Robinson et al. (2017) uses commercial buildings characteristics to feed a gradient boosting model to predict energy consumption. Anđelković and Bajatović (2020) include historical weather information to predict gas consumption in Serbia, while Vinagre et al. (2015) uses external data, such as temperature and solar radiation, to guide a neural network model. Yu (2018) proposes a two-step approaches that that uses buildings engineering estimators and demand to come with a corrected consumption prediction. Kumar and Jain (2010) focus on Markov based methods to predict energy consumption from different sources in India.

In this project, we will use data from Calgary's municipal buildings historical energy consumption to understand the energy consumption of different types of structures, and how Calgary's efforts to GHG emission reductions are represented in the data. Using the historical energy consumption, we try different algorithms to forecast future consumption from different sources. We also use a *multivariate adaptive regression splines* (MARS) model (Friedman, 1991) to study the impact analysis of the change of light bulbs of street lighting from 2016.

CANADA ON THE WORLD'S CO_2 EMISSIONS SCENARIO

Using data gathered by Ritchie and Roser (2020), we can analyze and identify where Canada is in the world's CO_2 emissions scenario. Figure 2 is the world's annual CO_2 emissions from 1750 to 2019. Each colored area represents a period of trend of the emissions. The first trend change seems to happen after the end of the industrial revolution (1840), followed by a noisy low trend period during the two great wars. The two next periods (1945 to 1980 and 1980 to 2011) show the highest increase of CO_2 emissions, but the second one (starting from 1980) shows a small drop of the trend. The last period, from 2011 to 2019, is the post Paris agreement (2005, blue vertical line), and a strong drop of the trend started. However, the emissions are still the highest ever recorded.

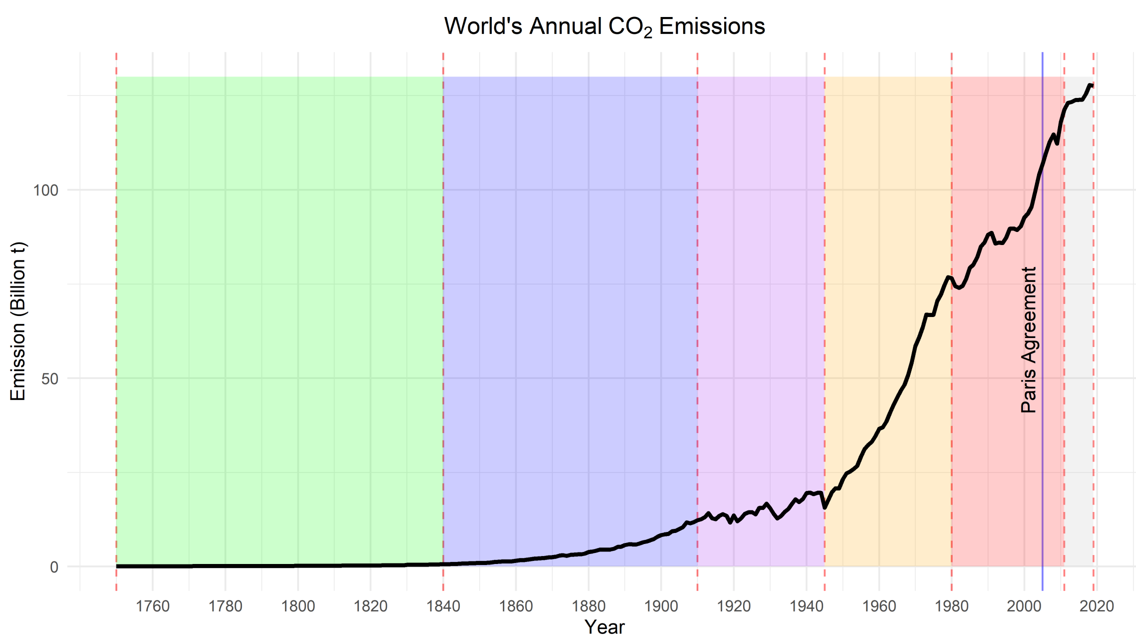

FIG. 2. World's annual CO_2 emissions. Each colored area represents a period of trend of the emissions.

Checking the cumulative CO_2 top 10 emitters countries or groups from 1980 to 2019 (Figure 3), where each color is the percentage for each emission source, it's populated by the industrialized countries and the European Union. In the top 3, United States (first) and European Union (third), the source of the emissions is dominated by oil, followed by coal. For China (second), the dominant source is coal. Canada is in the 8^{th} place, and the dominant sources are oil and gas, respectively.

Looking at mode recent years, 2018 (left) and 2019 (right) in Figure 4, the top 3 emitters

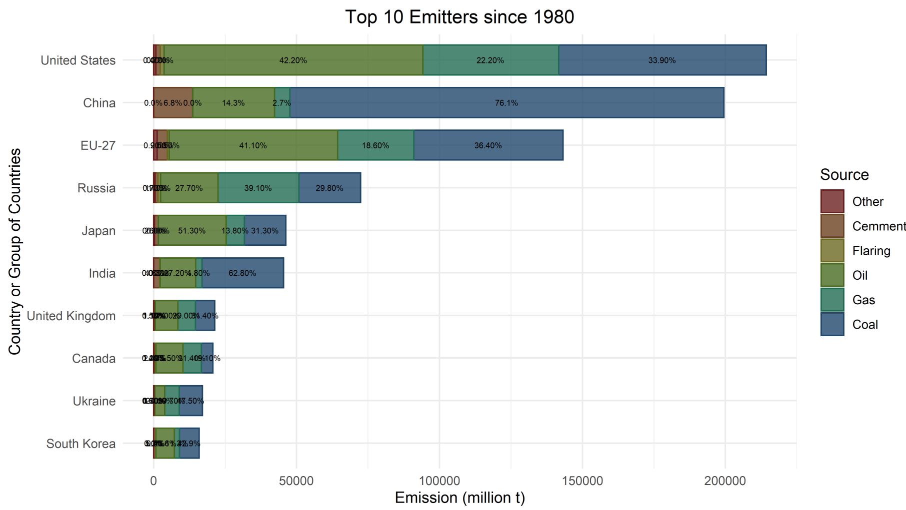

FIG. 3. Cumulative CO_2 top 10 emitters countries or groups from 1980 to 2019. Each color is the percentage for each emission source.

are the same, but China tops the charts, following the economical surge that started when they opened up their market in the 80's (Xiong and Xu, 2021). Canada figured in the top 10 (9^{th} in 2018, leaving the charts in 2019, with a drop of the absolute value on CO_2 emissions, and still dominated by oil and gas, respectively.

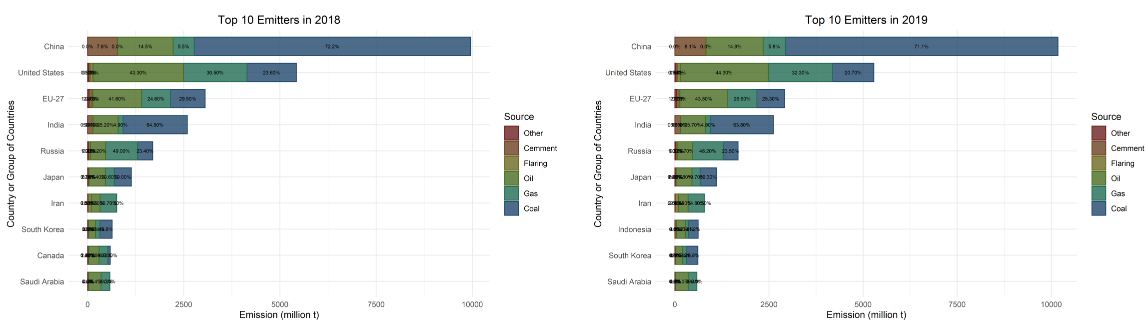

FIG. 4. Top 10 CO_2 emitters countries in 2018 (left) and 2019 (right).

To understand how the CO_2 emissions evolved in Canada over the years, Figure 5 shows the annual relative changes in CO_2 emissions per capita production-based (green, domestically produced emissions), consumption-based (red, related to transportation of imports), and the GDP per capita. As GDP per capita increases, emissions per capita decrease, indicating on a higher efficiency economic system.

Looking at absolute numbers, Figure 6 annual emissions discretized by source. They shifted from coal to oil dominant economy and emissions in the 1950's decade. This comes from the observation in Figure 1 of the top emitter sector in Canada, with the *transportation* (second) being dominated by burning of oil derivatives, while for the *electricity and heat*, even though most of electricity generation comes from hydro and nuclear plants (Canada, 2020b), around 18% of generated electricity comes from burning oil, gas, and coal, and the main source of heating in Canada is natural gas and electricity.

This suggests that Canada's strategy to reduce CO_2 emissions needs to tackle those two sectors first. Transportation's reductions can be achieved by replacing oil burning autos to

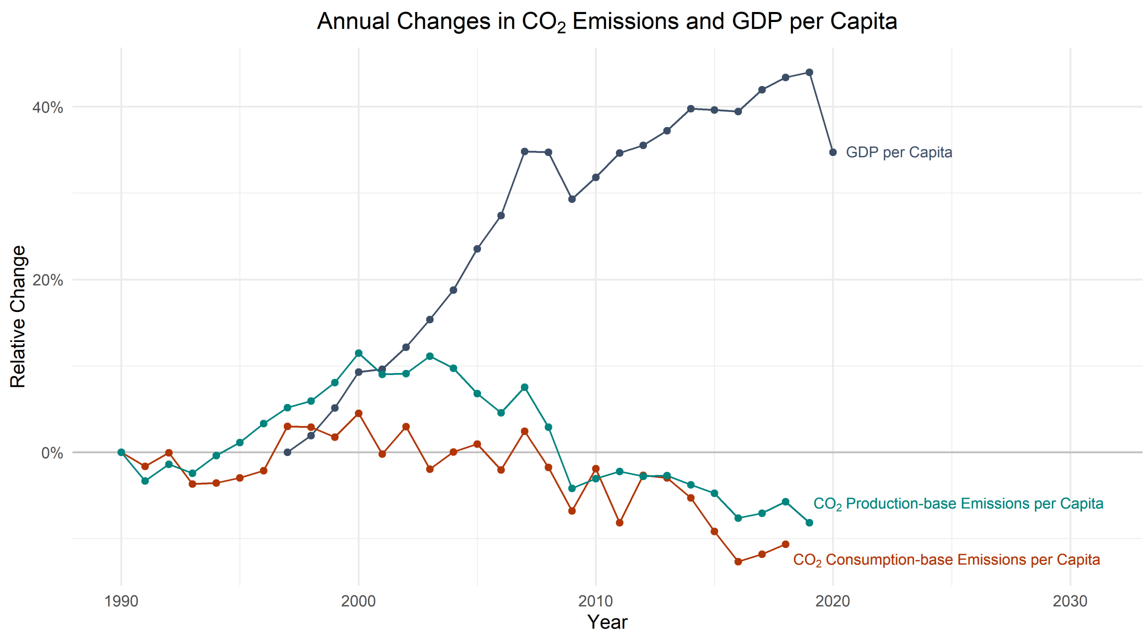

FIG. 5. Canada's annual CO_2 emissions and GDP per capita.

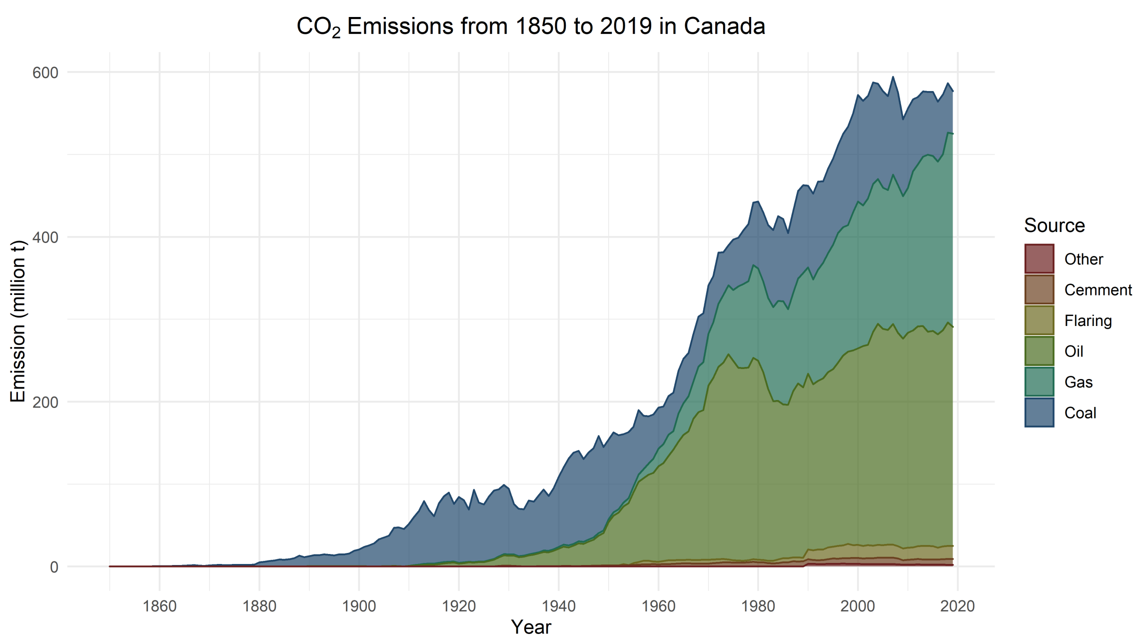

FIG. 6. Canada's annual CO_2 emissions discretized by source.

electric ones, and the dependency would be transferred to the electricity sector. This brings us to the main target of this project: understanding energy generation and usage is essential to forecast future demands and decision make. We are doing the analysis for municipal buildings in Calgary for this purpose.

Calgary is just a city in Canada, and therefore a "small" contributor to the country's GHG emissions, we need to optimize and increase efficiency in all fronts, and everybody need to do their part.

CALGARY MUNICIPAL BUILDINGS' ENERGY CONSUMPTION

Raymond (2018) gathered information of monthly energy consumption and generation (in kWh) over time (from 2014) of Calgary's municipal buildings. The data contains columns that allow the table to be divided in different categories for the data analysis: type of energy, type of business (offices, roads and transit, waste, etc.), facility name, year, and month. By grouping the data over different classes, we can summarize the data in different ways. However, it only contains the consumption and no information of the building itself, and such data can be important to understand and forecast future energy usage. It is a quite complex and rich dataset, so we can start to analyse it more globally and then refine to more local observations.

Overall Energy Consumption

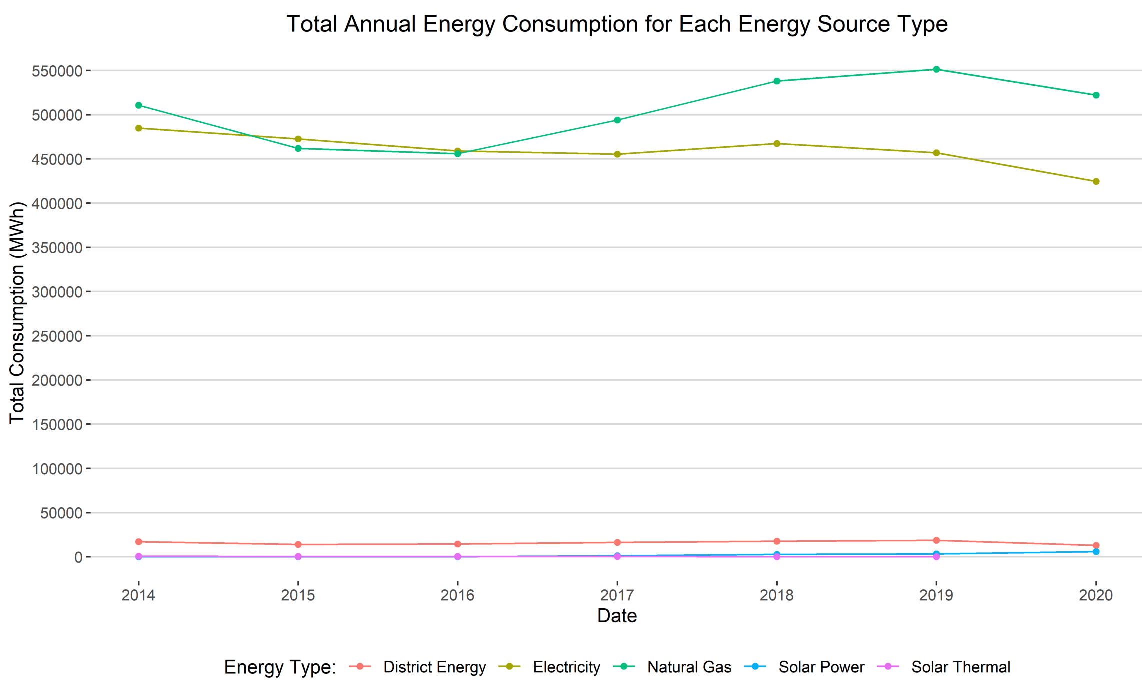

FIG. 7. Annual Calgary's municipal buildings consumption by energy type.

Figure 7 is the total Calgary's annual municipal buildings consumption by energy type from 2014 to 2020. There are 5 different sources of energy in the data: district energy (for heating a group of buildings using mainly natural gas), electricity (from the grid), natural gas (mainly for heating), solar power, and solar thermal (for heating). Electricity and natural gas are the main source of energy for the municipal buildings. In a quick observation, the electricity consumption looks to be following a reduction trend, while the opposite seems to happen for the natural gas consumption (the exception is 2020, but it is an unique year due to the COVID pandemic).

Flipping to to monthly consumption (Figure 8), it becomes clear the high seasonality of the energy consumption. It is more evident on the natural gas consumption, when the demand increases drastically during the Winters (due to heating). Such seasonality is also

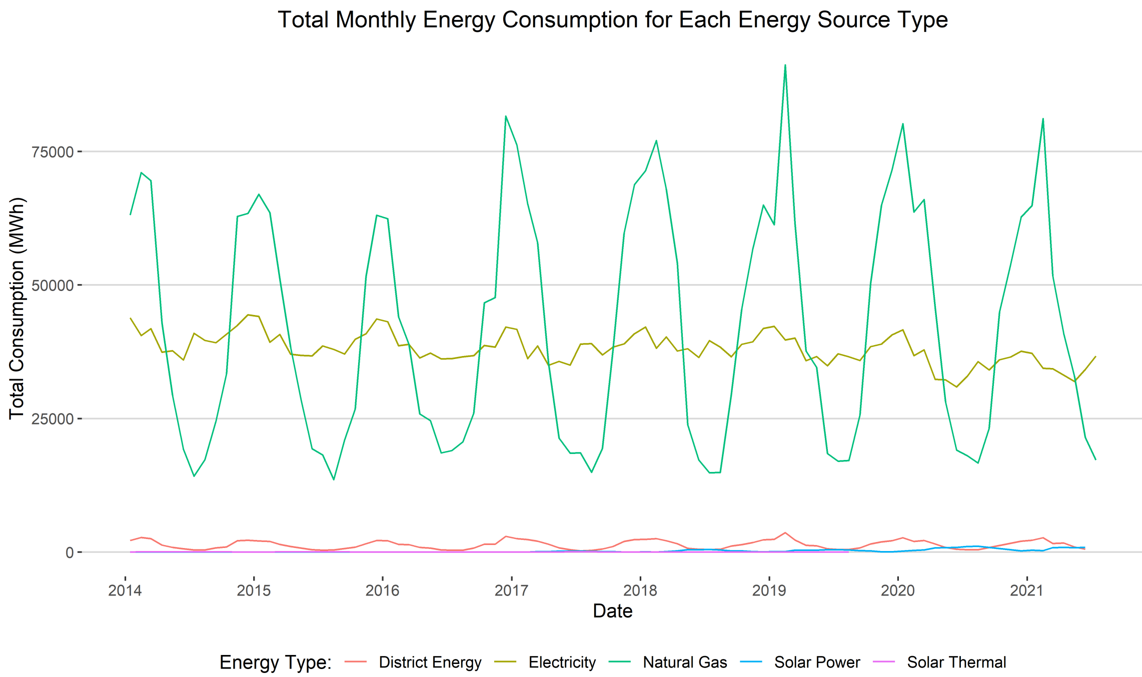

FIG. 8. Monthly Calgary's municipal buildings consumption by energy type.

observed, in a lower amplitude, for the electricity consumption, that can be a combination of heating and lighting during shorter daylight periods.

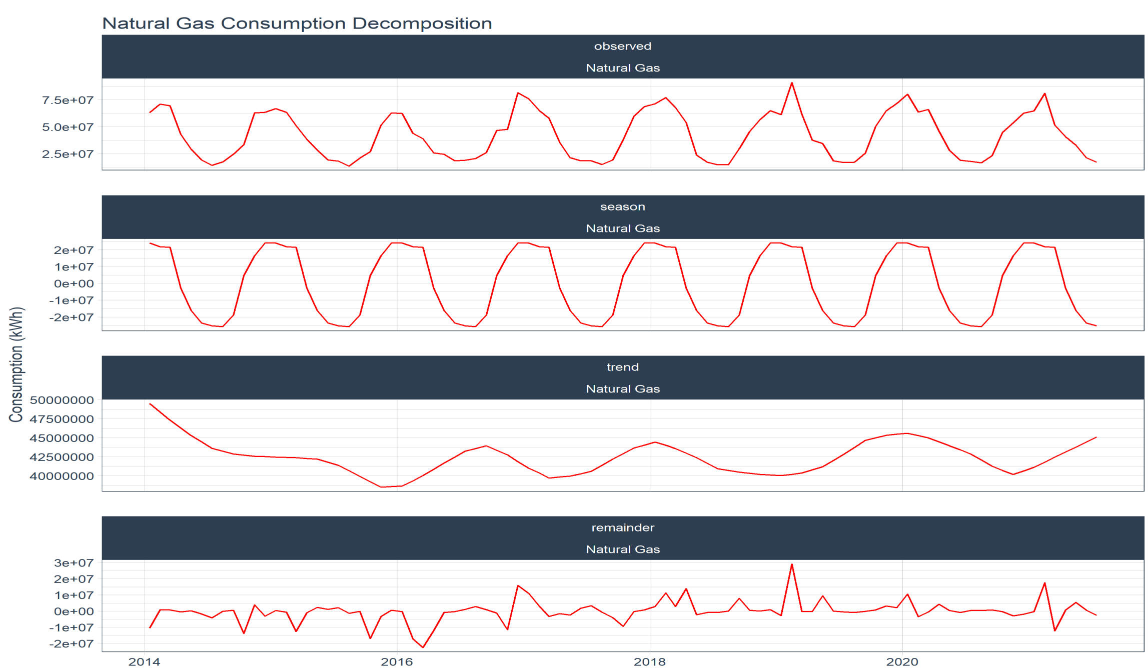

FIG. 9. Time series decomposition of Natural Gas usage.

Figure 9 is the time series decomposition of natural gas consumption. On the top is the original time series, followed by the estimated seasonality, showing higher consumption during the winters. The third plot shows the calculated trend, which tries to compensate for the local events on different years, such as the lower consumption during the 2015-2016 Winter. Lastly is the remainder (or the residuals), and outliers become more visible, as the higher values in the 2018-2019 winter (due to lower temperatures, as shown in Figure 10), as well the lower consumption during "warmer" winters of 2014-2015 and 2015-2016.

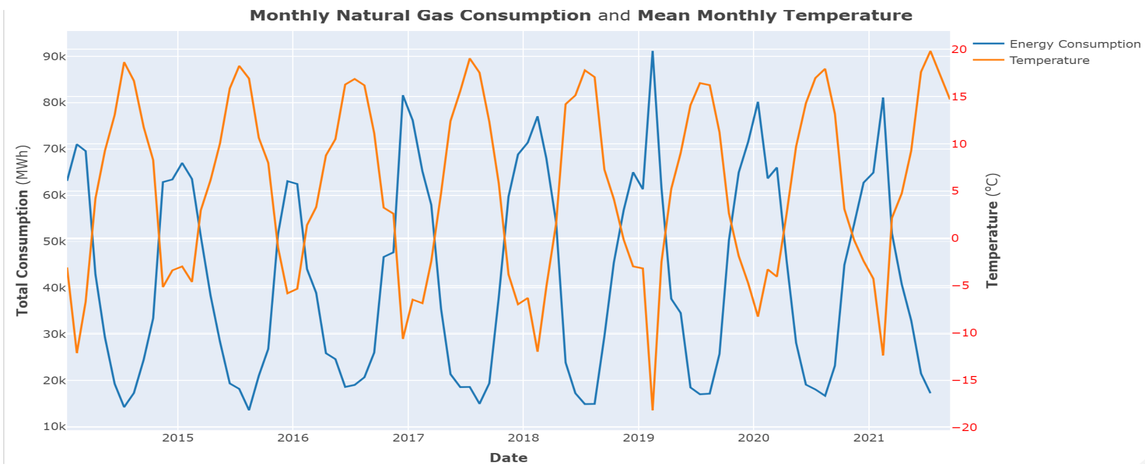

FIG. 10. Correlation of natural gas consumption and temperature.

Natural gas consumption seems highly correlated with temperature (Figure 10), with higher consumption connected to colder winters and lower consumption inversely connected to warmer summers, pointing that natural gas consumption is largely dominated by heating.

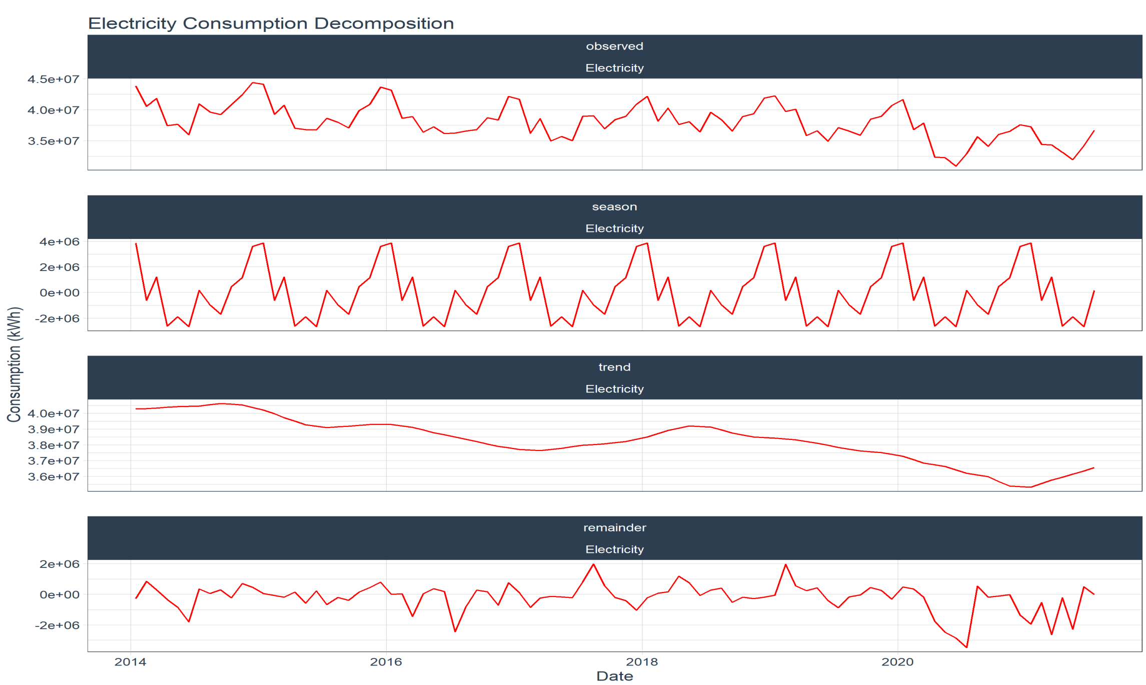

FIG. 11. Time series decomposition of Electricity usage.

Electricity consumption also presented some seasonality in Figure 8, and Figure 11 shows its time series decomposition. On the top, the observed consumption shows an apparent descent trend over the years combined with a seasonality behavior. The second plot is the decomposed seasonality, while the third one is the trend, confirming a decrease in the consumption. The residuals look relatively well behaved until 2020 and 2021, during the COVID pandemic, though outliers years.

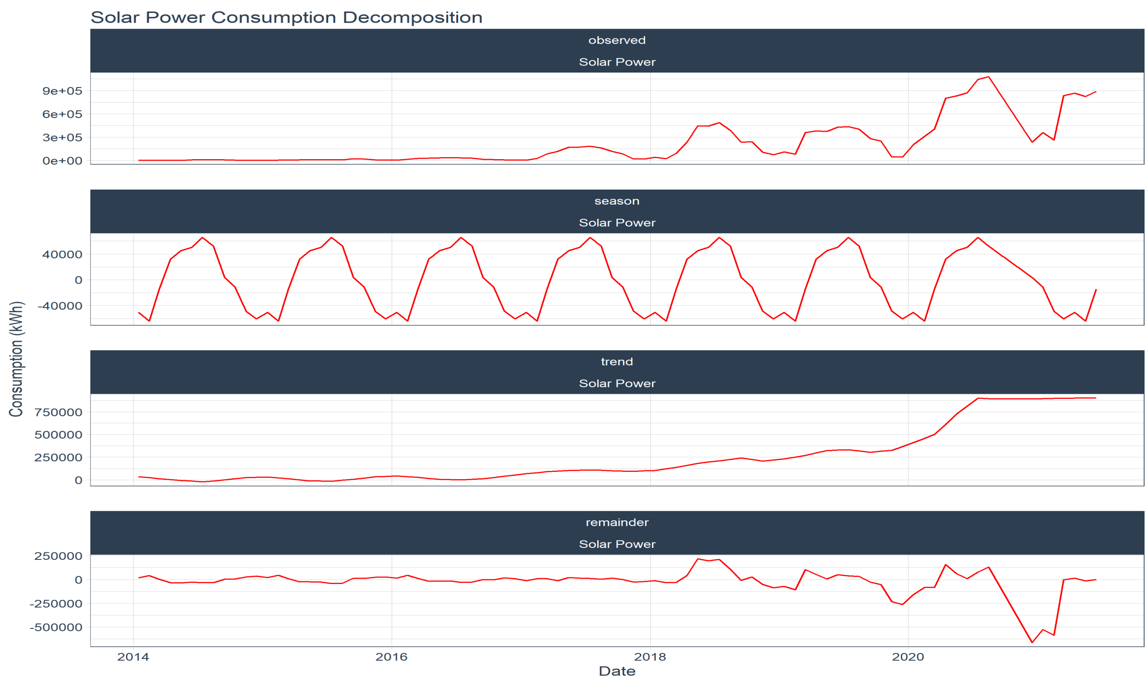

FIG. 12. Time series decomposition of Solar Power usage.

As part of Canada's reduction of CO_2 missions, investment on renewable energy is a promising reality. Figure 12 is the time series decomposition of solar energy consumption. Until the beginning of 2016, consumption was virtually zero by Calgary's municipal buildings, and the trend decomposition shows a increase of solar power usage over the years. There is also the seasonality that is inverse of the electricity and natural gas: higher consumption happen during the Summer, when the days are longer.

Top Consumers

The next step is to start digging deeper into the data and check the consumption of different classes. First, we will analyze the *business* categories, as it is divided by groups of buildings of similar characteristics, such as management facilities, water treatment, roads, and others. There are a total of 20 different business classes.

Business classes consumption is shown in Figure 13, considering all sources of energy. The seasonality is strongly observed in every business, and it's clear that some business consume more energy than others, which could be explained by the type of facilities inside each business class, as well the number of facilities for each class. Most of the classes have stable over time, without any clear trend, except for the decreased consumption of *Roads*, and increased consumption of *Waste - Recycling Services*.

Figure 14 shows the top 10 *Business* consumers of electricity, which is dominated by

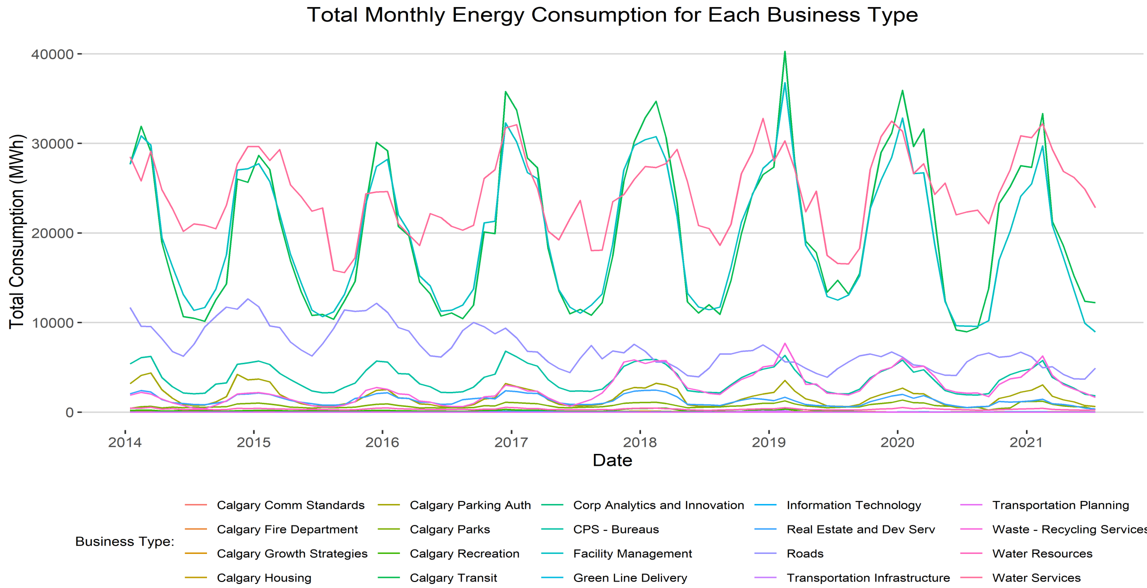

FIG. 13. Total monthly energy consumption of each business class.

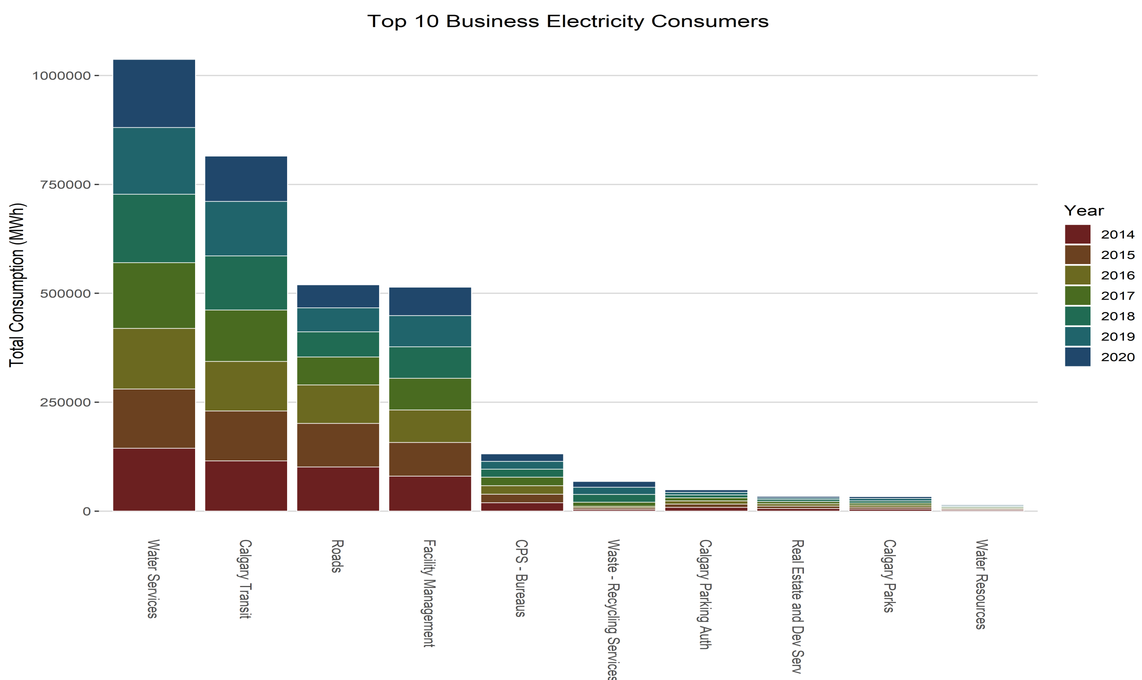

FIG. 14. Top 10 *Business* consumers of electricity.

Water Services (water treatment), followed by the *Calgary Transit*, that are the CTrains, stations, etc. *Roads* and *Facility Management* (office and entertainment buildings) are tied. The colors represent the total consumption of each year from 2014 to 2020. It's interesting to observe as yearly consumption of Roads is decreasing since 2016, and this class will be further analysed later on.

Observing the top 10 *Business* consumers of natural gas (Figure 15 points Facility Man-

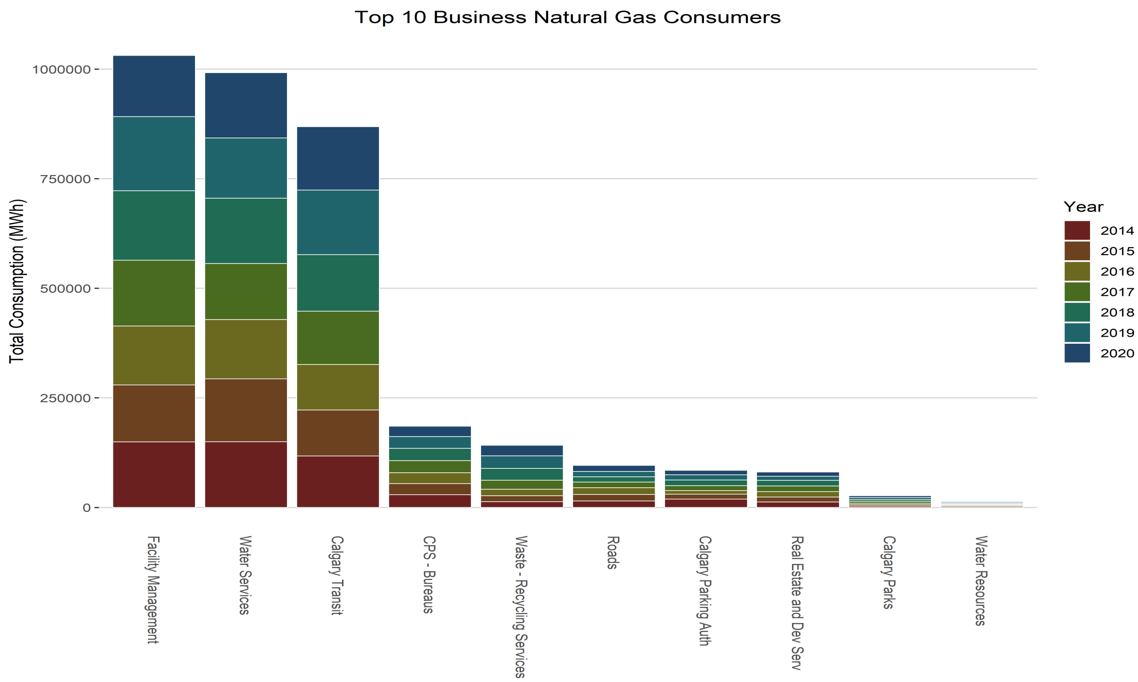

FIG. 15. Top 10 *Business* consumers of natural gas.

agement as the top consumer, followed closely by Water Services, while Calgary Transit is not far behind. Roads has relatively low natural gas consumption. For Facility Management, note the drop of consumption in 2020, probably due to the COVID pandemic, and workers were at home office mostly of the year. As the top Business consumer, we will analyze *Facility Management* deeper later in this report.

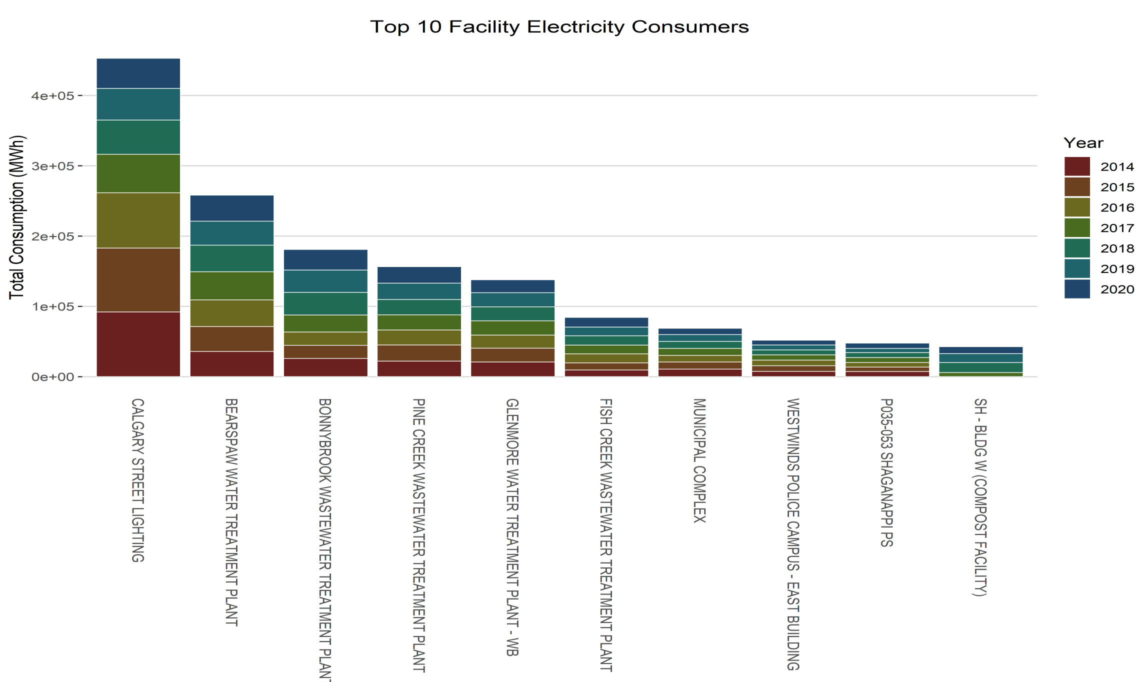

FIG. 16. Top 10 facilities consumers of electricity.

Analyzing consumption deeper, Figure 16 shows the top 10 facilities consumers of electricity. *Calgary Street Lighting* is in the top of the chart, with the observation of the drop in consumption starting in 2016. According to Raymond (2018), this drop is related to changing of more efficient light bulbs, and seems to have effectively made positive effect to the reduction of CO_2 emissions. The top-6 is completed with water treatment facilities, and the last 4 are a combination from different business.

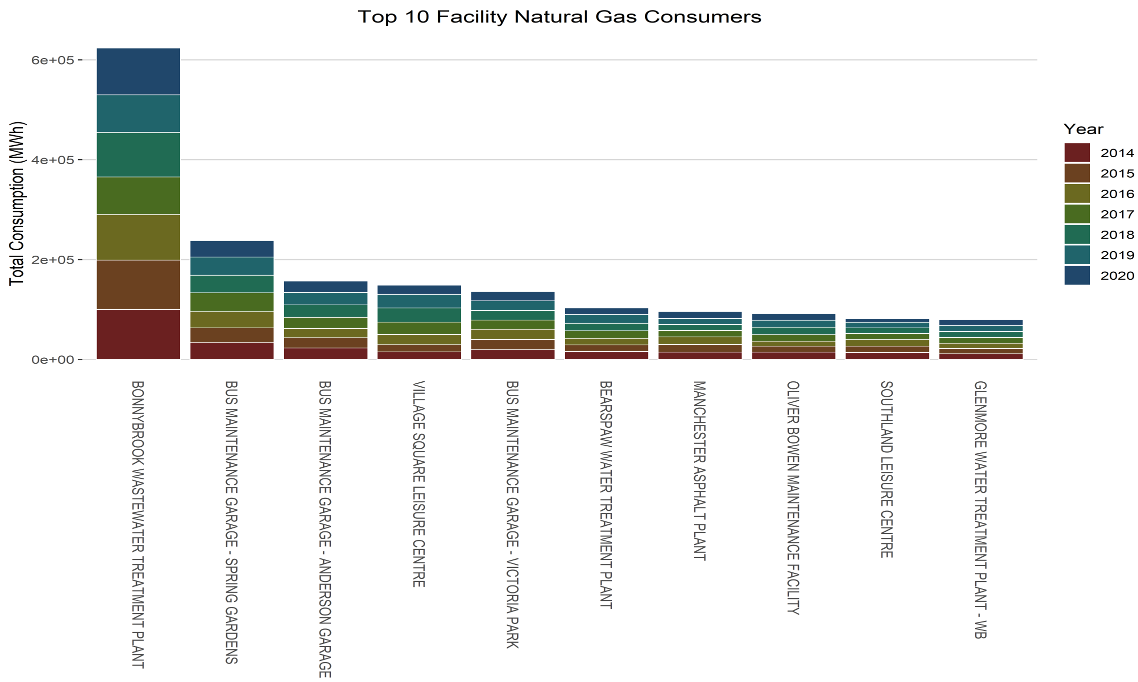

FIG. 17. Top 10 facilities consumers of natural gas.

At last, Figure 17 show the top 10 facilities that consumed more natural gas from 2014 to 2020, which is topped by the *Bonnybrook Wastewater Treatment Plant*. The top-5 is then completed by *Bus Maintenance Garages* and the *Village Square Leisure Centre*.

Facility Management

As the top natural gas consumer type of business, we will go deeper in the *Facility Management* class by analyzing top consumer facilities, for both electricity and natural gas, and understand how City's actions are impacting the consumption.

Starting with the top 10 electricity consumers from 2014 to 2021, we can check how the consumption behaves in time in Figure 18. The top consumer is the *Municipal Complex*, which follows a decreasing trend. Seasonality is less clear for most of the buildings, but for the municipal complex, higher consumption seems to happen during the Summer, probably due to AC. Looking at the *Village Square Leisure Centre*, there is a big drop in consumption from mid 2016 to mid 2017, moving it to the second highest consumer to the last one of the top 10. According to the City of Calgary, the building went through renovations in 2017 to increase energy efficiency, as well adding a new NHL size rink, which affected the natural gas consumption (Figure 19).

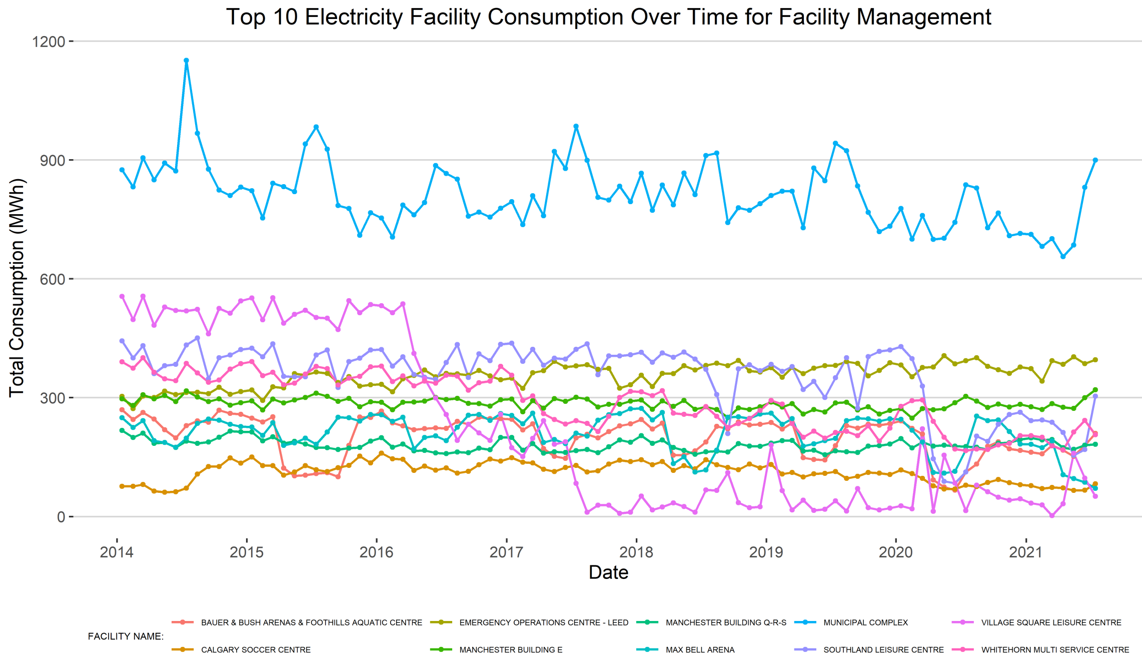

FIG. 18. Top 10 facilities consumers of electricity in *Facility Management*.

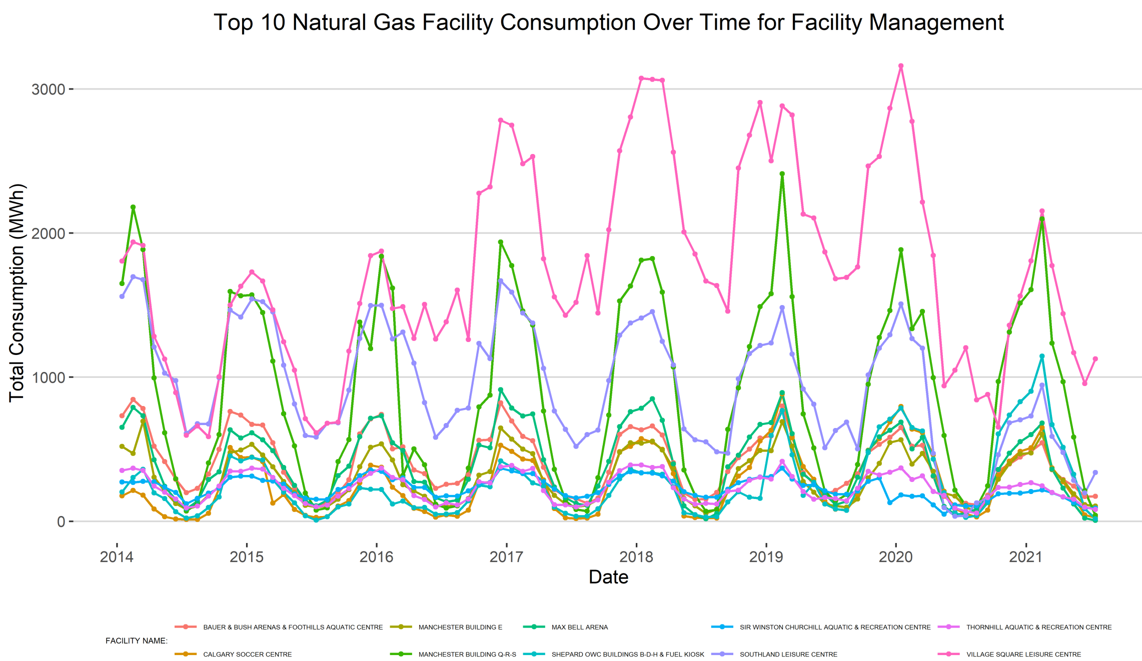

FIG. 19. Top 10 facilities consumers of natural gas in *Facility Management*.

Natural gas consumption, that is mostly used for heating, has a different order in the top 10 consumers (Figure 19). Village Square Leisure Centre was among the top 3 consumers until the Winter of 2015-2016, and then jumped to a solitary top consumer. As pointed before, the building went through renovations that included an extension by adding a NHL size rink. A drop is observed in 2020 and 2021, due to the COVID pandemic. Interestingly, the Municipal complex is not among the top 10 natural gas consumers, even though it is the top electricity consumer. To make decisions on how to reduce energy consumption, we need to understand each building characteristics, that implies in buildings like the Village Square Leisure Centre to be a relatively low electricity consumer to be a distant higher natural gas consumer, and exactly the opposite happens for the Municipal complex.

FIG. 20. Municipal Complex (left) and Village Square Leisure Centre (right).

The Calgary Municipal Complex (Figure 20, left), also referred as the *New City Hall*, is the seat of the government of the city of Calgary. It contains 14 floors and 74.000 m^2 of floor area with around 2.000 employees. It is a large building, which justifies its high electricity consumption (lights, elevators, appliances, etc). The Village Square Leisure Centre (Figure 20, right) is a recreation centre with 22.260 m^2, and contains pools, rinks, and gyms. It is considerably smaller (in floor area) than the Municipal complex, but it uses significantly more natural gas. The Municipal building, as an office building, is relatively easier to heat than the Village Square, that has high ceilings, hence uses more energy to heat the indoor space. Also, as a leisure centre, Village Square contains heated pools. All this sum to a high consumption of natural gas. This shows how it is important to have these types of information in the data for more detailed forecasting and decision making.

ENERGY CONSUMPTION FORECASTING

Forecasting the future energy usage is important for governments to make decisions and planning how to action to reduce CO_2 emissions. As we are missing specific buildings characteristics information, forecasting will be done more globally for the electricity and natural gas consumption. Modeling was done with models that uses the historic data itself to predict values in the future, and the models of choice are the *Facebook Prophet* (Taylor and Letham, 2017), the *multivariate adaptive regression splines*, or *MARS* (Friedman, 1991), and the *SARIMA* (Cowpertwait and Metcalfe, 2009) combined with the *XGBoost* algorithm (Chen and Guestrin, 2016). The XGBoost implements a *gradient boosting* (Hastie et al., 2001) solution. To evaluate the forecasting results, first they are applied on a period of the data that contains real measures of consumption, but are not used for the modeling. After the models are trained on the whole data to predict the future consumption.

Electricity Forecasting

This section consists on the electricity forecasting for the whole Calgary corporate buildings, and we are assuming that past energy consumption is enough to predict the future. The evaluation is done over the last six months of the real data. From Figure 11, the time series decomposition of the electricity consumption showed a seasonality effect and a descending trend, and those are the features the three models look for.

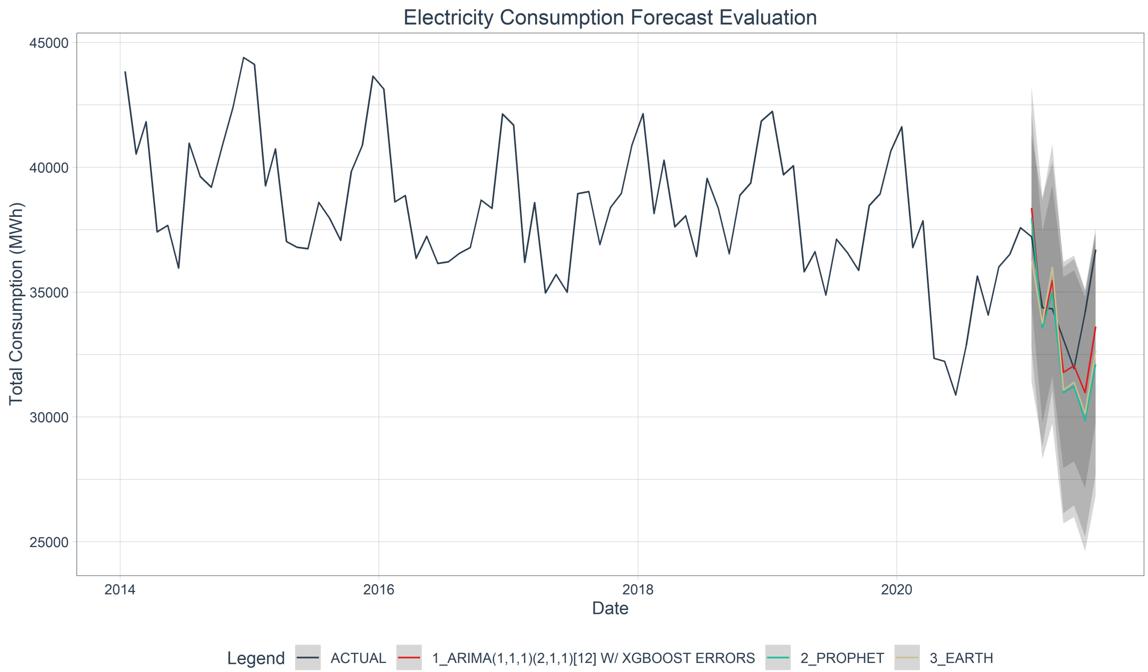

FIG. 21. Electricity forecasting evaluation.

Figure 21 shows the prediction of the three different models in overlap with the last six month of the true data. The SARIMA + XGBoost (in red) seems to be following the true values closer than the Prophet (green) and MARS (yellow, and called EARTH in open source libraries). The three models are, apparently, using a similar seasonality unit, but with different trends for the prediction.

Retraining the models with the whole data and calculating the forecasting for three years in advance (Figure 22, it is interesting how they are diverging from each other by following different trends. The SARIMA + XGBoost (red) follows the global descending trend of the model and was less affected by the 2020 and 2021 COVID pandemic years, while the Prophet (green) follows a more recent trend (as the model calculates localized trends), and is heavily impacted by 2020 and 2021. MARS (yellow), is a model that also calculate a regression model for different ranges of the data using *basis functions*, and is predicting an increasing electricity consumption, probably because it is following the the 2020-2021 trend.

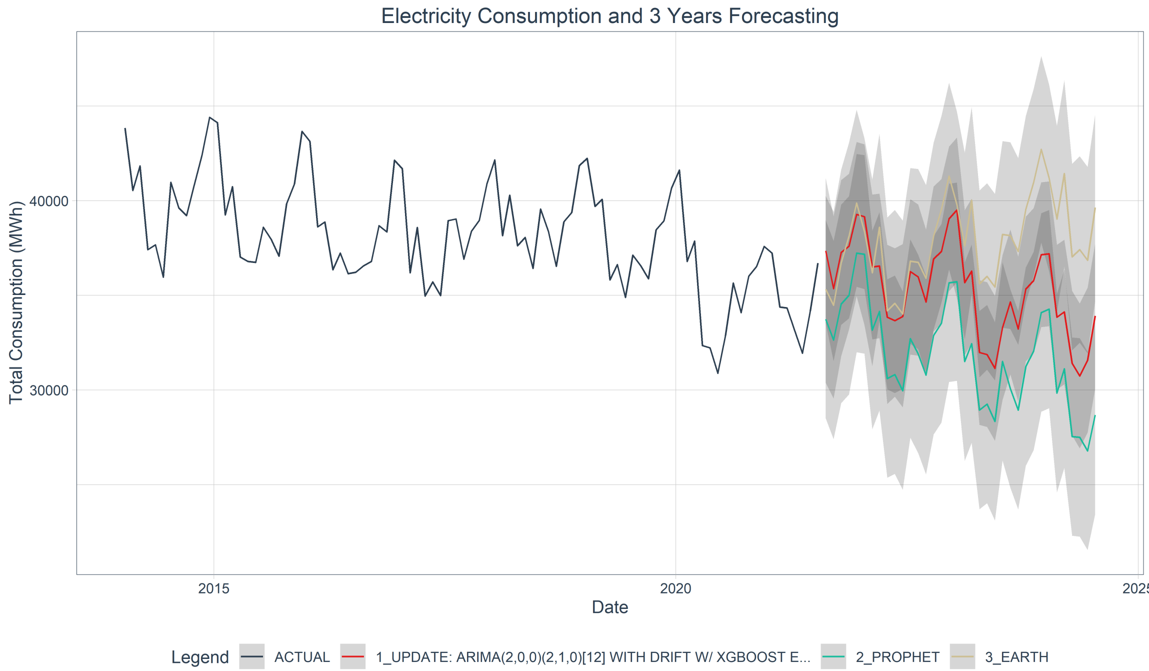

FIG. 22. Electricity forecasting for the next 3 years.

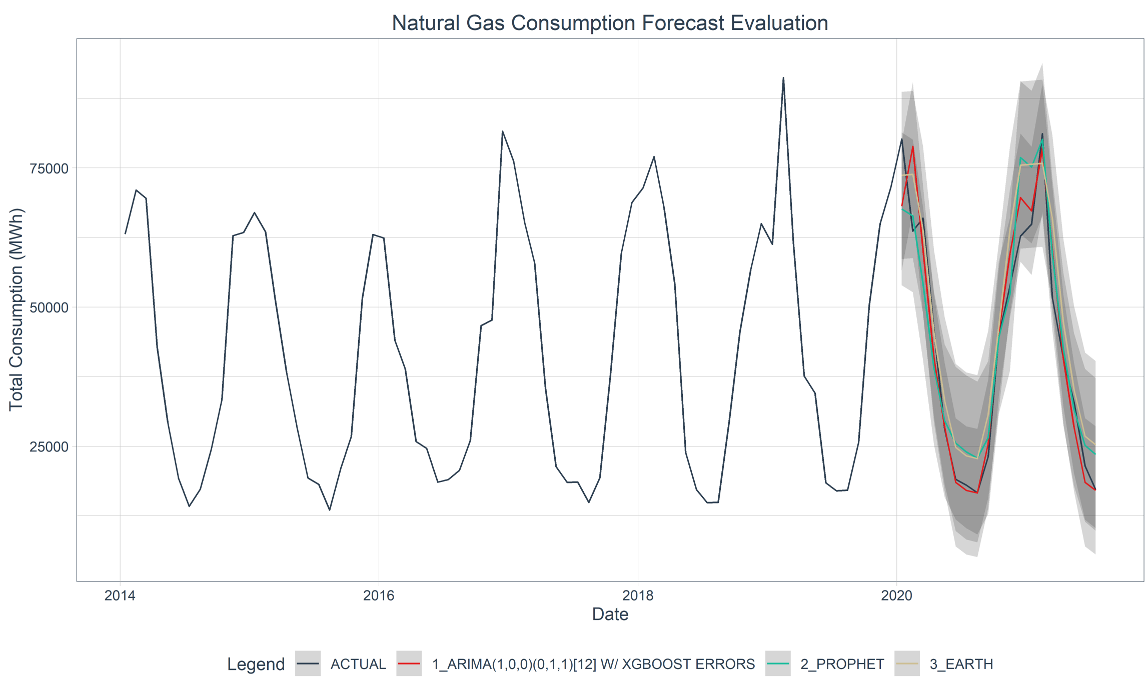

FIG. 23. Natural gas forecasting evaluation.

Natural Gas

For the natural gas forecasting, we used the years 2020 and 2021 for evaluation and Figure 23 shows the evaluation of the three models. As for the electricity, natural gas consumption predictions seems to be better capitalized by the SARIMA + XGBoost model (red), while Prophet (green) and MARS (yellow) are close to each other, but with different peaks (Prophet is slightly better in this part).

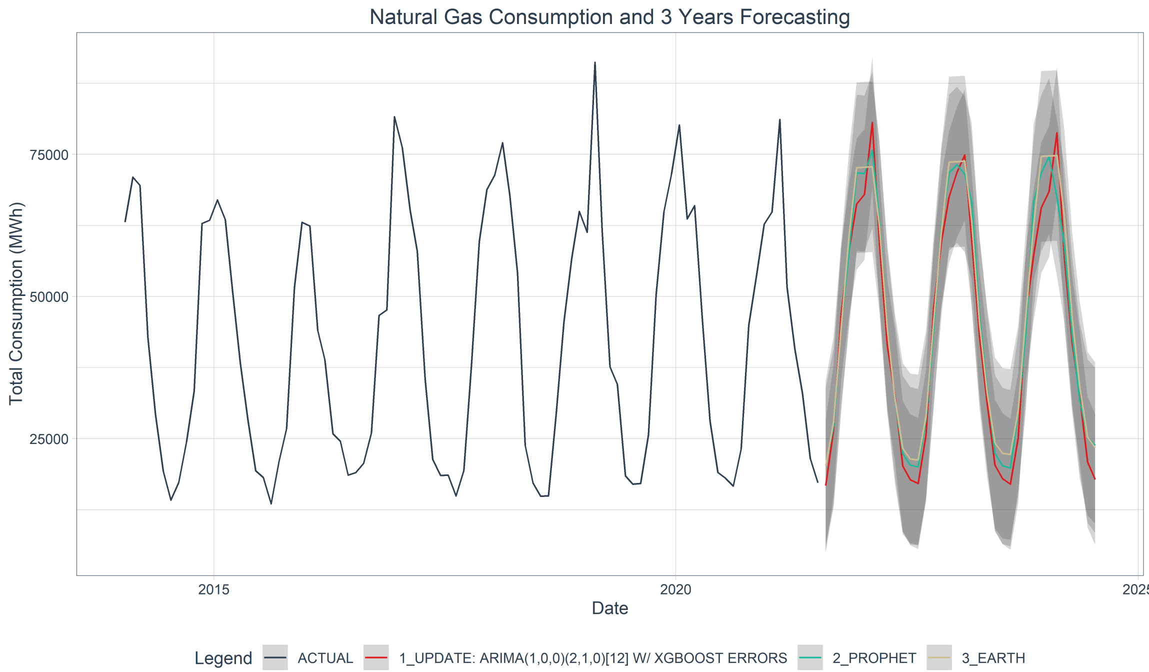

FIG. 24. Natural gas forecasting for the next 3 years.

Forecasting 3 years in advance (Figure 24), the three models are close to each other, and the trends are neither increasing or decreasing, implying the same level of natural gas consumption for the next three years.

CALGARY STREET LIGHTING IMPACT ANALYSIS

As we pointed earlier in the report, in Figure 13, *Roads* class is reducing its electricity consumption over the years and it is mainly dominated by changes on the *Calgary street lighting*, and we will calculate the difference of energy of the real values against a forecasting for the same period.

Figure 25 shows the electricity consumption of the Calgary street lighting from 2016 to September 2021. Energy usage started to follow a descending trend from 2016 to 2019 and then stabilized. According to Raymond (2018), this is due to the decision of the Government of Calgary to change the lamp bulbs of the street lights to more energy efficient ones. To calculate how much energy was saved, we calculated the consumption forecasting from 2016 to 2021 training a model with data from 2014 to 2015.

As only two complete cycles (2 years) are used for training, the SARIMA + XGBoost and Prophet were not able to capture the seasonality of the data. MARS showed to be stable and were able to do such forecasting with a small amount of data. Figure 26 shows in red what is the calculated electricity consumption of the street lights if the bulbs were not changed. **From January 2016 to September 2021, the savings on electricity consumption was of about 212 GWh**. An average house in Alberta uses around 7200 kWh per

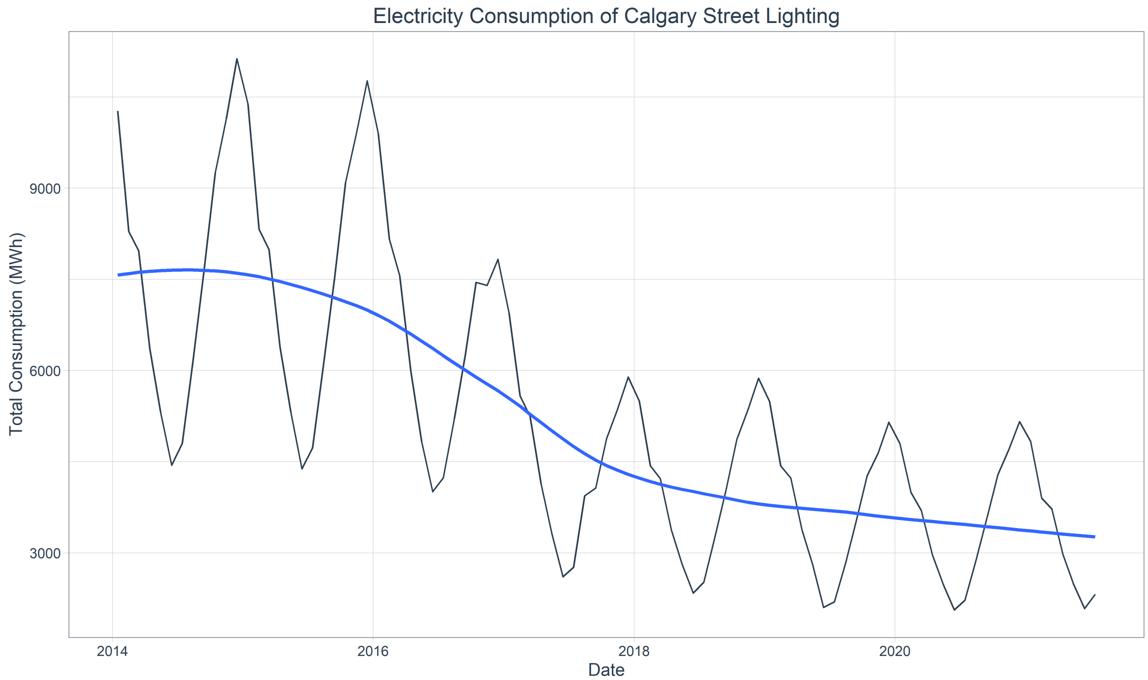

FIG. 25. Calgary street lighting electricity consumption.

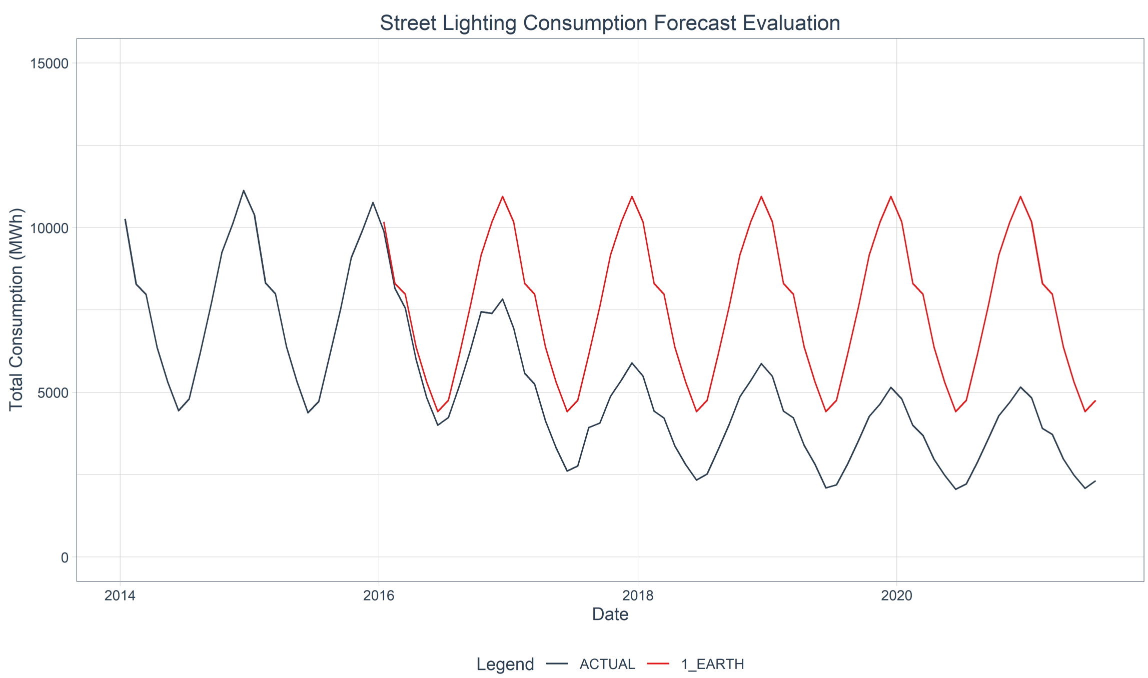

FIG. 26. Impact analysis of the Calgary street lighting reduction of electricity consumption.

year, and the savings on street light consumption could feed more than 5000 houses from 2016 to 2021.

CONCLUSIONS

CO_2 emissions are pointed to as the main cause of Global Warming, and countries around the world are working to reduce their domestic emissions. Canada set to get to zeronet emissions by 2050 and is taking action on different fronts. Although the emissions per capita are reducing, the absolute emissions of the country are still increasing over the years. As part of the country's efforts, the Government of Calgary has set the same goal.

We analyzed the Calgary corporate buildings data, which contains energy consumption from different types of municipal facilities and pointed that the overall electricity consumption in the city is declining, while natural gas consumption seems to be following an opposite trend. As a decision-making tool, forecasting models can predict what will be the future energy consumption. However, for that, more complete data is required, containing not only the energy consumption of each building but as well structural information about the same.

We performed forecasting of global electricity and natural gas consumption using three different models: SARIMA + XGBoost, Facebook Prophet, and MARS. The first one showed to behave better with the seasonality and outliers, predicting a steady reduction of electricity consumption for the next three years, while the natural gas consumption will, if no action is taken, continue at the same level.

Lastly, we did the impact analysis of the reduction of electricity consumption of the Calgary streetlights since 2016, due to an action of the Government of Calgary to change the light bulbs to more energy-efficient ones and estimated that the savings are feeding the equivalent of more than 5000 houses in Alberta.

ACKNOWLEDGEMENTS

We thank the sponsors of CREWES for continued support. This work was funded by CREWES industrial sponsors and NSERC (Natural Science and Engineering Research Council of Canada) through the grant CRDPJ 543578-19. The 1^{th} author was supported by the Canada First Research Excellence Fund, through the Global Research Initiative at the University of Calgary. We thank Soane Mota dos Santos for the suggestions, tips and productive discussions.

REFERENCES

Anđelković, A. S., and Bajatović, D., 2020, Integration of weather forecast and artificial intelligence for a short-term city-scale natural gas consumption prediction: Journal of Cleaner Production, **266**, 122,096.
URL https://www.sciencedirect.com/science/article/pii/S0959652620321430

Bourdeau, M., qiang Zhai, X., Nefzaoui, E., Guo, X., and Chatellier, P., 2019, Modeling and forecasting building energy consumption: A review of data-driven techniques: Sustainable Cities and Society, **48**, 101,533.
URL https://www.sciencedirect.com/science/article/pii/S2210670718323862

Buis, A., 2019, A degree of concern: Why global temperatures matter: NASA, last accessed 03 November 2021.
URL https://climate.nasa.gov/news/2865/a-degree-of-concern-why-global-temperatures-matter/

Canada, 2020a, Canada's actions to reduce emissions: Government of Canada.
URL https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/reduce-emissions.html

Canada, 2020b, Electricity facts: Government of Canada.
URL https://www.nrcan.gc.ca/science-and-data/data-and-analysis/energy-data-and-analysis/energy-facts/electricity-facts/20068

Chen, T., and Guestrin, C., 2016, Xgboost: Proceedings of the 22nd ACM SIGKDD International Conference on Knowledge Discovery and Data Mining.
URL http://dx.doi.org/10.1145/2939672.2939785

Cowpertwait, P. S., and Metcalfe, A. V., 2009, Non-stationary models, *in* Introductory Time Series with R, chap. 7, Springer, 137–157.

Friedman, J. H., 1991, Multivariate adaptive regression splines: The Annals of Statistics, **19**, No. 1, 1–67.
URL http://www.jstor.org/stable/2241837

Hastie, T., Tibshirani, R., and Friedman, J., 2001, The elements of statistical learning - data mining, inference, and prediction: Springer, second edn.

Kumar, U., and Jain, V., 2010, Time series models (grey-markov, grey model with rolling mechanism and singular spectrum analysis) to forecast energy consumption in india: Energy, **35**, No. 4, 1709–1716, demand Response Resources: the US and International Experience.

Lawton, D. C., Dongas, J., Osadetz, K., Saeedfar, A., and Macquet, M., 2019, Development and Analysis of a Geostatic Model for Shallow CO2 Injection at the Field Research Station, Southern Alberta, Canada, Cambridge University Press, 280–296.

Macquet, M., Lawton, D. C., Saeedfar, A., and Osadetz, K. G., 2019, A feasibility study for detection thresholds of co2 at shallow depths at the cami field research station, newell county, alberta, canada: Petroleum Geoscience, **25**, No. 4, 509–518.
URL https://www.earthdoc.org/content/journals/10.1144/petgeo2018-135

Raymond, R., 2018, Corporate energy consumption: City of Calgary.
URL https://data.calgary.ca/Environment/Corporate-Energy-Consumption/crbp-innf

Ritchie, H., and Roser, M., 2020, Co_2 and greenhouse gas emissions: Our World in Data, https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions.

Robinson, C., Dilkina, B., Hubbs, J., Zhang, W., Guhathakurta, S., Brown, M. A., and Pendyala, R. M., 2017, Machine learning approaches for estimating commercial building energy consumption: Applied Energy, **208**, 889–904.
URL https://www.sciencedirect.com/science/article/pii/S0306261917313429

Somu, N., Raman M R, G., and Ramamritham, K., 2021, A deep learning framework for building energy consumption forecast: Renewable and Sustainable Energy Reviews, **137**, 110,591.
URL https://www.sciencedirect.com/science/article/pii/S1364032120308753

Taylor, S. J., and Letham, B., 2017, Forecasting at scale: PeerJ Preprints, **5**, e3190v2.

UNEP, and UNEP-DTU, 2021, Emissions Gap Report 2021: The Heat is On: UNEP DTU Partnership.
URL https://www.unep.org/resources/emissions-gap-report-2021

Vinagre, E., Gomes, L., and Vale, Z., 2015, Electrical energy consumption forecast using external facility data, *in* 2015 IEEE Symposium Series on Computational Intelligence, 659–664.

Wei, N., Li, C., Peng, X., Zeng, F., and Lu, X., 2019, Conventional models and artificial intelligence-based models for energy consumption forecasting: A review: Journal of Petroleum Science and Engineering, **181**, 106,187.
URL https://www.sciencedirect.com/science/article/pii/S092041051930600X

Xiong, J., and Xu, D., 2021, Relationship between energy consumption, economic growth and environmental pollution in china: Environmental Research, **194**, 110,718.
URL https://www.sciencedirect.com/science/article/pii/S0013935121000128

Yu, D., 2018, A two-step approach to forecasting city-wide building energy demand: Energy and Buildings, **160**, 1–9.
URL https://www.sciencedirect.com/science/article/pii/S0378778817328876