WIND EMISSIONS DISPLACEMENT IN ALBERTA, CANADA

by

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INTRODUCTION

We are living in a time where climate issues are one of the utmost important and main topics of debate in our society. Climate change will change our way of life; therefore, we need to understand the causes of these changes and the consequences they could have.

The literature available, and reported in this paper, about new climate and energy issues, are telling us that we must diversify from fossil fuels due to all the devastating effects of these resources on the atmosphere. CO_2 is the main culprit for earth temperature growth, cause now the atmospheric concentration of CO_2 is over 400ppm, being 300ppm the maximum not exceeded in the last 800.000 years *[1]*. As coal is one of the main CO_2 pollution sources, we must find other energy sources that helps us to protect the environment and make the electric system more sustainable.

In the coming future, there will be several major effects on the planet as a result of the way we obtain energy. Therefore, we must change to a more sustainable system of harnessing energy, through renewable resources, in order to reduce the impact of climate change.

Among these devastating effects is the rising of sea level, risking millions of lives in the upcoming years in coastal areas and islands *[2]*. Other effects include the diminishing water supply for some isolated areas, worsening air quality and unpredictable weather effects *[2]*.

This is why the reports of the Intergovernmental Panel on Climate Change (IPCC) or the Paris Agreement have increasing relevance. By 2100, the temperature of earth will have increased a range between 1.5 and 2ºC *[2]*, with catastrophic consequences, as well as being a point of no return for our planet. In order to keep the temperature growth under a maximum of 1.5ºC, these reports conclude that we must reduce a 45% of the CO_2 emissions by 2030.

Some countries are more ambitious than others, as many are leading this revolution at least in a political theory, but others are against it as many people around the world refusing to believe climate change is real. The main polluting countries are the US, China and India *[1]*. Although many countries are phasing out coal source, global emissions rate is still rising *[3]*.

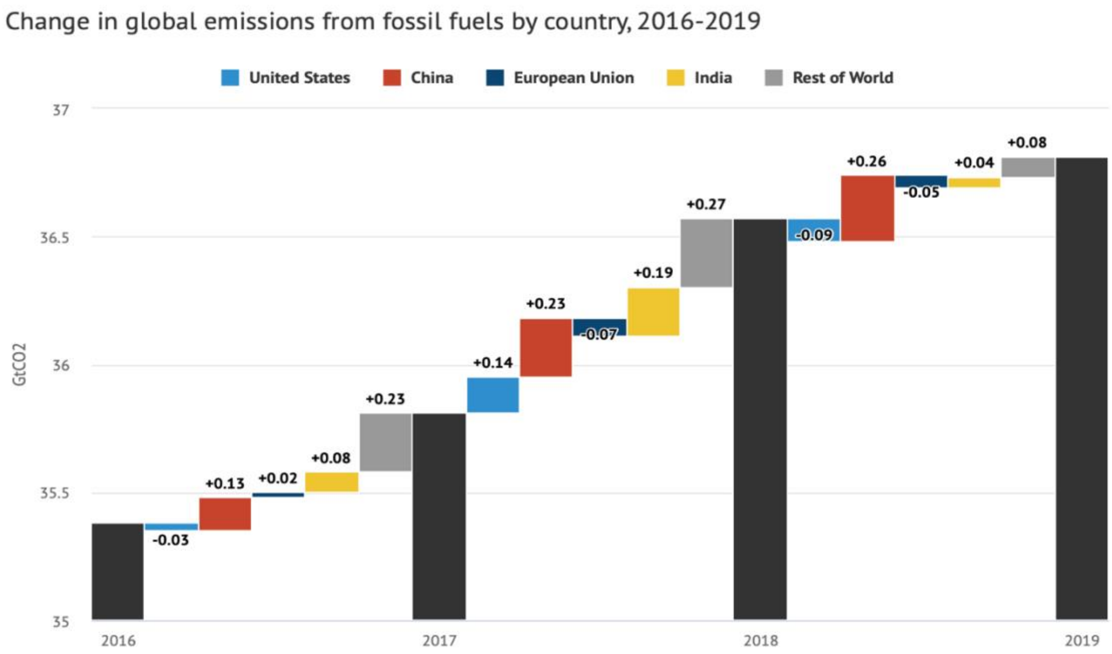

***Figure 1**: Change in global emissions from fossil fuels [3]*

In the recent years we have faced one of the worst episodes of fires all around the globe, putting in danger millions of human lives and even more wild animals' lives. The protection of the amazon, the California fires or the huge catastrophe in Australia are the signs we must acknowledge in order to ensure good environment for the future generations.

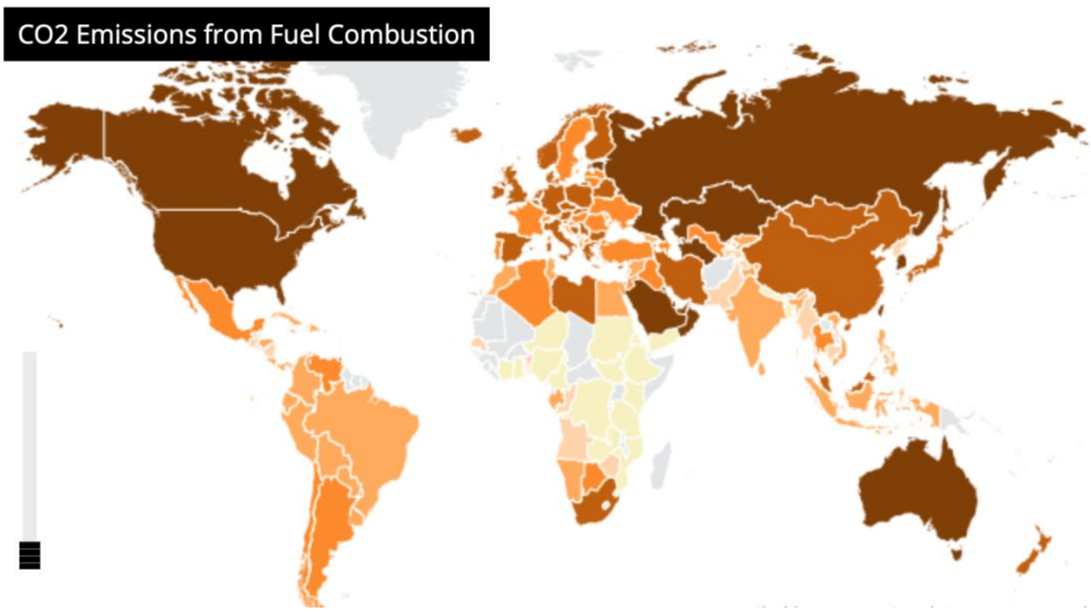

***Figure 2**: Carbon emissions per capita in 2017 [4]*

If we look specifically at Canada, it must face a new reality as right now it is one of the largest polluters per capita in the world behind mainly Middle East countries, as can be seen in Figure 2. Even if Canada has one of the most important renewable infrastructures, as we will see later, is still one of the countries with more pollution, relatively speaking.

PROJECT

In this paper we will explore one of the most problematic pollution aspects along transport, that is the electrical sector. It causes 40% of greenhouse gases emissions in the world *[5]*, and reports say that if we achieve the goal of cutting those down to 90% and use renewable sources, the Paris Agreement goals can be achieved *[2]*.

The electric system is based on all the power plants which run to introduce electricity in the system and those power plants generates a lot of well-paid jobs. That means economies around the world need to move toward a greener employment system to replace that amount of jobs *[6]*.

Therefore, the aim of this paper is to establish the dependency of Canada on greenhouse gas sources and if the procedures that are applied right now are appropriate, or if some changes must be carried out. That dependency of Alberta and Canada as a whole will be compared. In order to do so, the electrical market in Alberta will be studied in order to know the source of the electricity, to establish the amount of renewable and non-renewable energy usage in Alberta. We will focus mainly on wind energy, as it is the most important renewable energy source in this province, although not in Canada.

The goal of this paper and research is to see the effects that wind energy generation has on the electrical market and what would happen if this important renewable source wasn't available.

The results we expect to encounter are reduction in emissions caused by the contribution of wind energy, how the pool price of every hour in the market is affected and what are the next steps so that we can reduce as much as possible coal usage and other greenhouse gas emissions. This will help us to know which kind of power plants are displaced from the market because of wind.

The data used in this project is AESO's market data *[7]*. Alberta Electric System Operator is an entity who manages the planning and operations of the interconnected electrical system. In this data can be found the type of plant that is introducing energy into the system, the pool price of every hour, and how much power is dispatched by each of those plants. Alberta is in a unique position as it is the only province in Canada where the electrical market data is public, therefore it is possible to study the connections between all private investors which generate electricity.

The effects of every hour over and eight-year time period will be studied, from 2012 to 2019, and the results of a hypothetical situation in which wind wouldn't be an energy source observed. This is of interest, because one of the main difficulties for investors to get involved with renewable energies is because it is said renewables are not a reliable source of income as they are too dependent on the weather.

Differences between Canadian and Albertan electrical markets is explored, and data is analyzed to know how dependent Alberta is on coal and locate the wind power plants in order to know what to expect of those power plants in the near future.

CANADA'S ELECTRICAL SYSTEM

The province of Alberta and Canada, as a whole country, are in totally different positions in the renewable sources electrical market race that is taking place nowadays around the world.

Alberta's energy sources will be discussed later when the behavior of the market is analyzed. With reference to Canada's electricity system, is moving towards a almost fulfilled by renewable sources. Right now, 67% of electricity comes from renewable and 82% from a non GHG emitting sources *[8]*, and the goal is to reach a 90% of non GHG emitting by 2030.

Canada stands as the 6th country of world electricity generation *[8]*.Reaching a 90% of electricity coming from renewable for such an important world generator can change how other countries behave.

World generation – 25,082 TWh (2016)

Rank	Country	Percentage of Total
1	China	25%
2	United States	17%
3	India	6%
4	Russia	4%
5	Japan	4%
6	**Canada**	**3%**
7	Germany	3%
8	Brazil	2%

Table 1*: World generation share by country*

For all the other energy sources and their share in Canada's electrical market, Figure 3 shows how renewables energies and coal have a huge position in the economy.

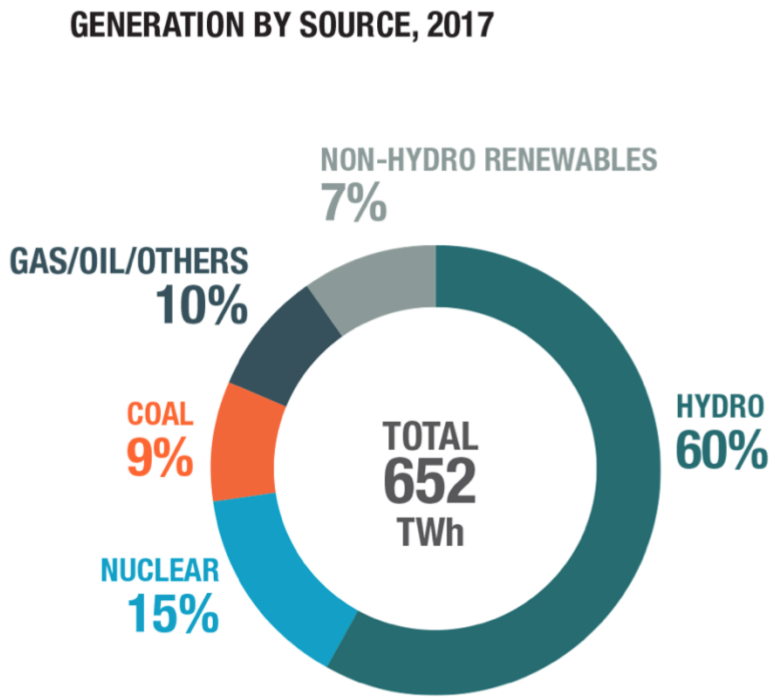

***Figure 3**: Generation by source in Canada [8]*

As nuclear is not a non-renewable source but is not either considered a GHG emitting source, clean sources have great importance in Canada. Later, we will see that in Alberta, coal share is much higher than in Canada, representing half of the electricity share.

Canada's extensive geography and existing reliance on hydropower make it a likely candidate for shifting to an entirely renewable domestic energy system. But at the same time, there is an uneven distribution of energy supply in the country, which could create problems if the areas of high renewable energy potential are not able to connect with areas of high energy use. Given that Canada doesn't have a robust nationwide transmission grid, this could become a problem for provinces highly dependent on energy sources in their own areas such as Alberta or Saskatchewan [9].

Regarding renewable energies, Alberta is positioned very far from the cleanest provinces. Hydropower is a huge energy source in the country, Canada being the second largest producer of hydroelectricity in the world after China [10]. Provinces such as Manitoba, Quebec, and British Columbia have almost 100% of their electricity coming from hydropower, meaning that the electrical market in these provinces is about to reach 0% GHG emissions.

The other renewable source present in the market is wind, but to a lesser extent. Wind is the fastest growing source of electricity in Canada and around the world, but currently it only represents 4% of electricity generation in the country [10].

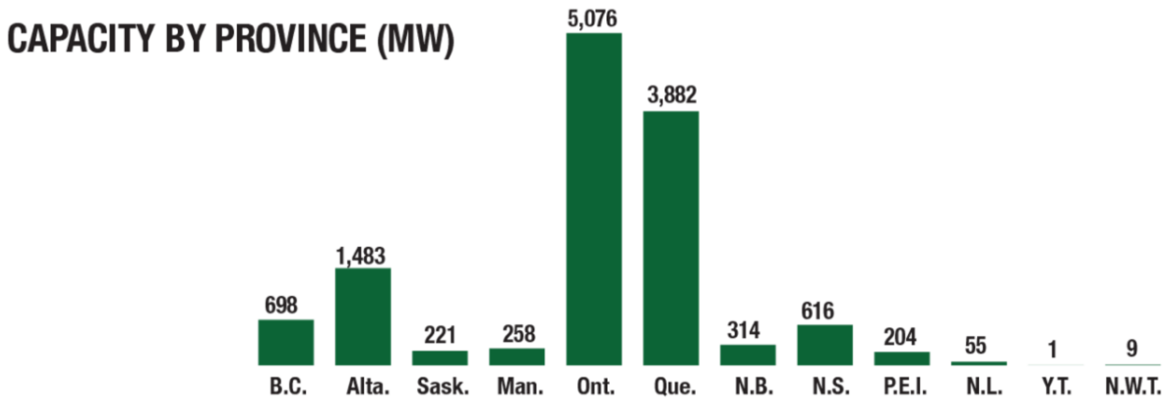

***Figure 4**: Installed capacity of Wind power for each Canadian province [10]*

Alberta has the third greatest wind installed capacity of all Canadian provinces, which is one of the reasons why there has been a lot of investment *[11]* so that on the upcoming years, Alberta can rely even more in wind energy.

Canada is the 9th country in the world generating electricity from wind, behind China, US and European countries, with a share of 2%. For instance, Spain is the 5th with 5% of world wind generation *[10]*.

One of the goals in Alberta is to reduce coal and rely more on renewables, and in case it's not possible on natural gas. In this province, there is not much opportunity to use hydro because of the lack of this type of power plants and the locations where water could be used for such a purpose, although investments are being done to increase hydro electricity generation share in Alberta. Investments in solar are done too, but in a lower scale due to the low capacity generation. The most important renewable energy right now with presence in the system is wind, but its input is so low that the market must be dependent on non-renewable energies, as will be analyzed in the next chapter.

Now that Alberta and other coal dependent provinces are investing on low cost wind projects, means target of renewable sources to rise to 90% of non-emitting for Canada is possible.

1. ALBERTA'S ELECTRICAL SYSTEM

1.1 ENERGY DISPATCHED

As mentioned, Alberta depends on the energies which are major emitters of greenhouse gases and pollution like coal or natural gas, around 19% of its electrical generation (Figure 3). In this chapter, the generation of each type of energy will be observed in the actual model of the electrical system in Alberta, so that one can see the difference of electricity market in this province compared to Canada as a whole.

Alberta has a competitive electrical market where generators can enter and compete at the best price possible, same as the other Canadian provinces, but with Canada being in a unique position as data is accessible for everyone through AESO. One can study the data and understand the effects renewable energies introduction has in the system. But this data is not accessible instantaneously, having less than half of the data for 2019 at the moment of this paper. So, from now on, all the analysis will be done for the period between 2012-2018, and apart from that, for the last 4 years including 2019 too. This last analysis will consider only the months included in 2019 for those 4 years, meaning only data from January to May for the second part of the analysis, which are 2016-2019.

This data is organized by the merit order, which accumulates the energy supplied to the system for each hour, ordered by price. The merit stops when hour demand is reached so hourly energy dispatched and demand match, and pool price is fixed. But at the same time, information on energy coming from other power plants that are not selected cause are bidding higher than pool price, is accessible too. It is possible to see which power plants have supplied energy into the system, which energy sources are them, the price bid and the emissions of that generation.

As mentioned, now we focus on the actual electrical system, and observe which sources are selected more often based on the price these power plants are bidding. So, at the end, it is possible to see how dependent the Alberta's electrical market is to a specific energy source.

These sources are mainly Coal (COAL), Cogeneration (COGEN) that comes from Natural Gas, Natural Gas (NGCC), Gas Turbine (SCGT), Solar (SOLAR), Hydro (HYDRO) and Wind (WIND). Other sources can provide energy to the system and will be specified in the following charts as Other. As this study aims to focus on the Alberta's activity electrical consumption, the imports will be considered cause it's an energy amount used to reach demand. On the contrary, exports will not be considered, as it is not an energy amount consumed in the area.

Figure 5 and 6 shows the electricity generation amount in the system per each type of energy and for every year, demonstrating the share of each energy source in the system.

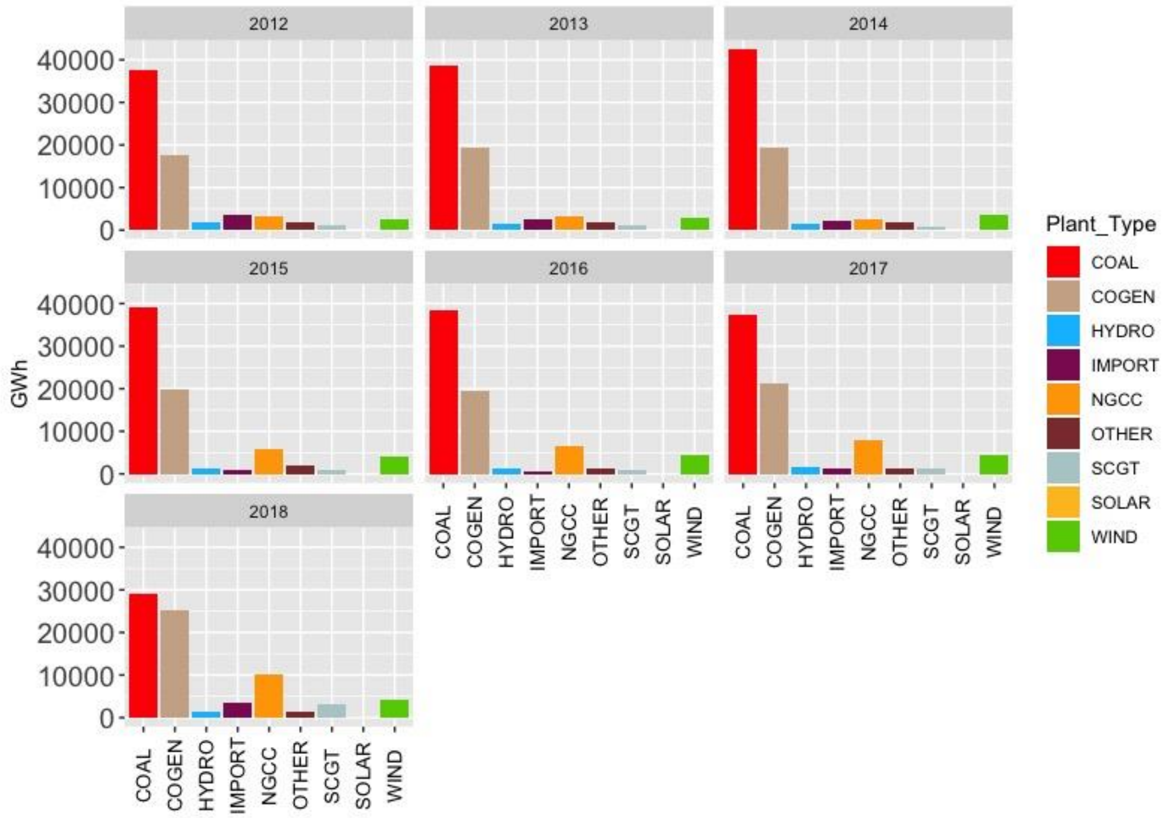

***Figure 5**: GWh dispatched in Alberta per each energy source for 2012-2018*

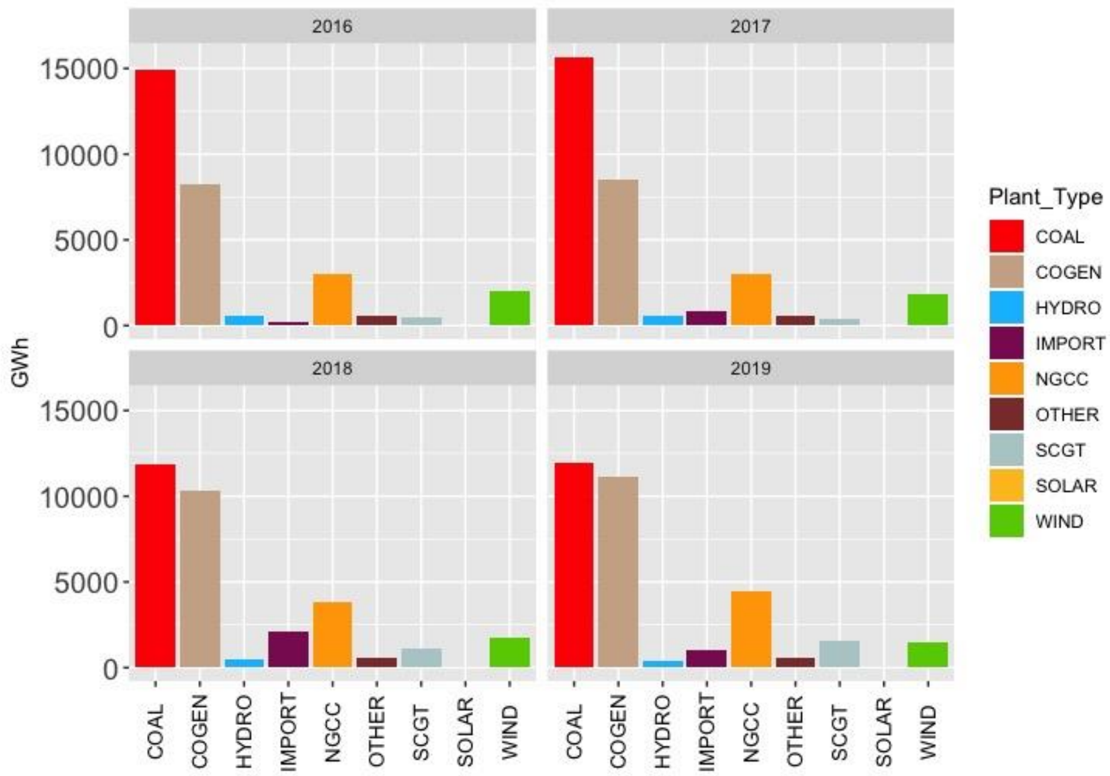

***Figure 6**: GWh dispatched in Alberta per each energy source for Jan-May*

Coal is the main energy source used for electricity in Alberta, representing approximately half of total electricity generation. Cogeneration, which mostly comes from natural gas, has the second greatest importance, followed by combined cycle natural gas.

Alberta is in a unique position, because it has an important amount of cogeneration power installed, due to the oil sands in the province. The cogeneration electrical capacity is expected to grow with the oil sand production growth *[12]*.

One can see that for the second part of the analysis, this includes 2019 data so the previous years only the first 5 months have been taken. Like 2018, in 2019 energy dispatched from coal is lower than previous years and that supply is replaced by cogeneration and Combined cycle natural gas.

As previously mentioned, because 2019 is not full of the actual data at his moment, in order to analyze 2019, this must be compared to the same period of time of the previous years.

In Table 2, one can see the share of each source of the total energy dispatched per each year, which will have importance later in understanding conclusions.

Year / Source	2012	2013	2014	2015	2016	2017	2018	2019
COAL	54	54	57	53	52	49	37	37
COGEN	25	27	26	27	27	28	32	34
HYDRO	2	2	2	2	2	2	2	1
IMPORT	5	4	3	1	1	2	4	3
NGCC	5	5	3	8	9	10	13	14
OTHER	3	3	3	3	2	1	2	2
SCGT	2	1	1	1	1	2	4	5
SOLAR	0	0	0	0	0	0	0	0
WIND	4	4	5	5	6	6	6	4

Table 2*: Share of each energy source for each year in %*

For 2019, only the available data has been analyzed, so it could be possible that source shares are different when talking about the whole year.

Even though solar has a very small share of the total, the table represents with (*) the years when it was possible to generate electricity from solar .

Local government has been trying to decrease coal importance in the market, with the introduction of carbon tax, for which the results can be first seen in 2018.

Although hydro has an important share of generation, and it is expected to grow more, it is lower than wind, being wind the most important renewable source which offers energy at a lower price than non-renewable sources. But as it has a low energy capacity input, in order to reach hourly demand, the system gets energy from GHG power plants, so wind is not enough to reach demand without the introduction of emitting energy sources, and at the end these are the most dominant sources.

There are many ways to decrease the importance of coal in the energy production system to help resolve the system dependency on this source. Two of them can be:

1- Applying a carbon tax would give the opportunity for other power plants and different sources to be introduced into the market before coal is able to. This seems to be the easiest way to get beneficial results. Although it was initially introduced in 2008, in the period of time studied in this paper the results can be first seen in 2018.

2- Attempting to decrease the energy demand so that renewable energy, natural gas and cogeneration are sufficient to meet the energy demand.

Results coming from applying a carbon tax can be seen in Figure 5 when in 2018 coal experienced a decrease of 22,1% compared to 2017, because other power plants supply before coal because they bid at a lower price. This helped reduce emissions as we will see later in this paper.

1.2 PRICE VS HOURLY ENERGY DISPATCHED

Another important chart to analyze is how energy is dispatched in an hour, and the curve that implies.

As mentioned, the merit order works selecting the first power plants that are bidding the energy amount at a lower price, introducing energy till hourly demand is matched. Some power plants desire is to get into the system at any cost, so they bid the energy supply at $0. Because of market behavior, next power plants are going to bid at a higher price than previous ones, till reach demand and fixing the pool price as the last price selected.

In the following, one can see how the hourly energy chart works for a random hour of 2018, in this case is 3/22/2018 4:00am.

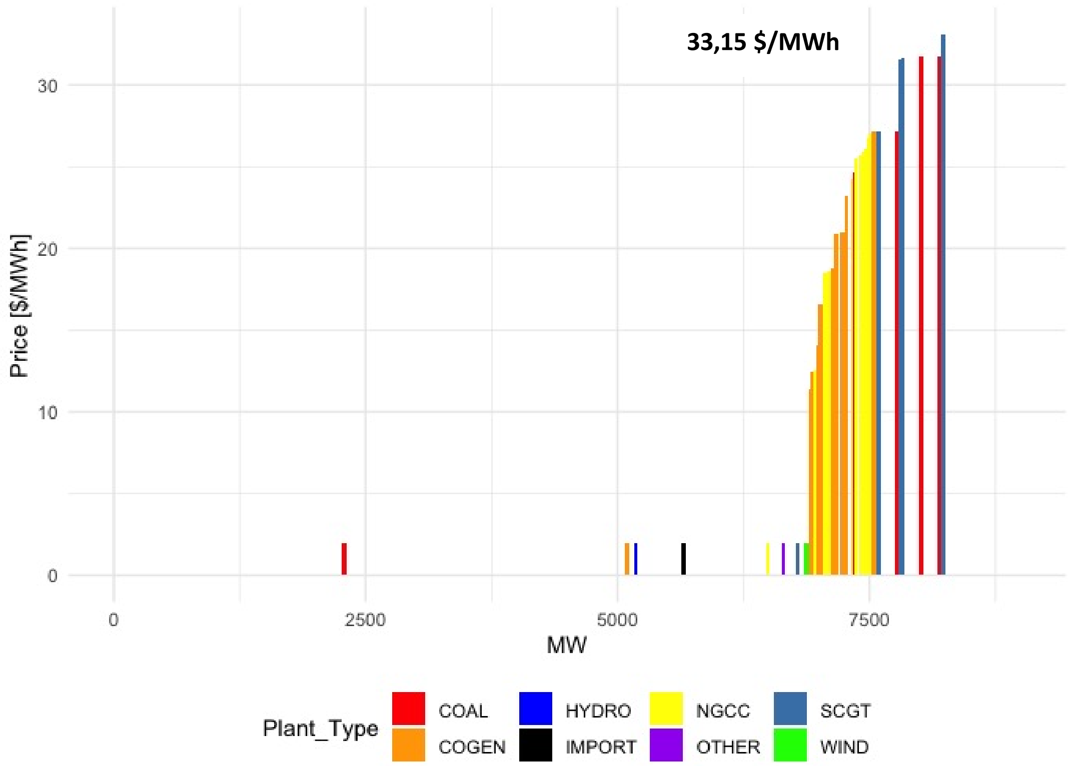

***Figure 7**: Hourly dispatched at a random selected date time*

Part of the energy needed for that time the is met with energy provided at $0 (in the chart has been changed for $2 so it can be represented), approximately 7000MW, but to meet the full demand other power plants bidding higher enter the market and set a higher cost (due to their higher production cost) which set a higher final cost for the whole market. The line for representing the energy price is almost exponential, and usually the last power plants to introduce energy are coal or cogeneration power plants, affecting at the pool price that is similar to the last price offered.

In this example, the last power plants suppling energy is a simple cycle gas turbine, fixing the pool price at 33,15. As all the energy supplied is sold at the pool price, in this case the 8228 MW will be sold at 33,15, meaning a wholesale of $272.758.

The next figure shows the same idea but referred to all 2018 data. This is done with the mean per each price bet of each source, meaning that each type of source is present on every price they have bid. All the power plants that were bidding to supply into the system are represented, with the price related. The x-axis represents the energy accumulated and the y-axis the price.

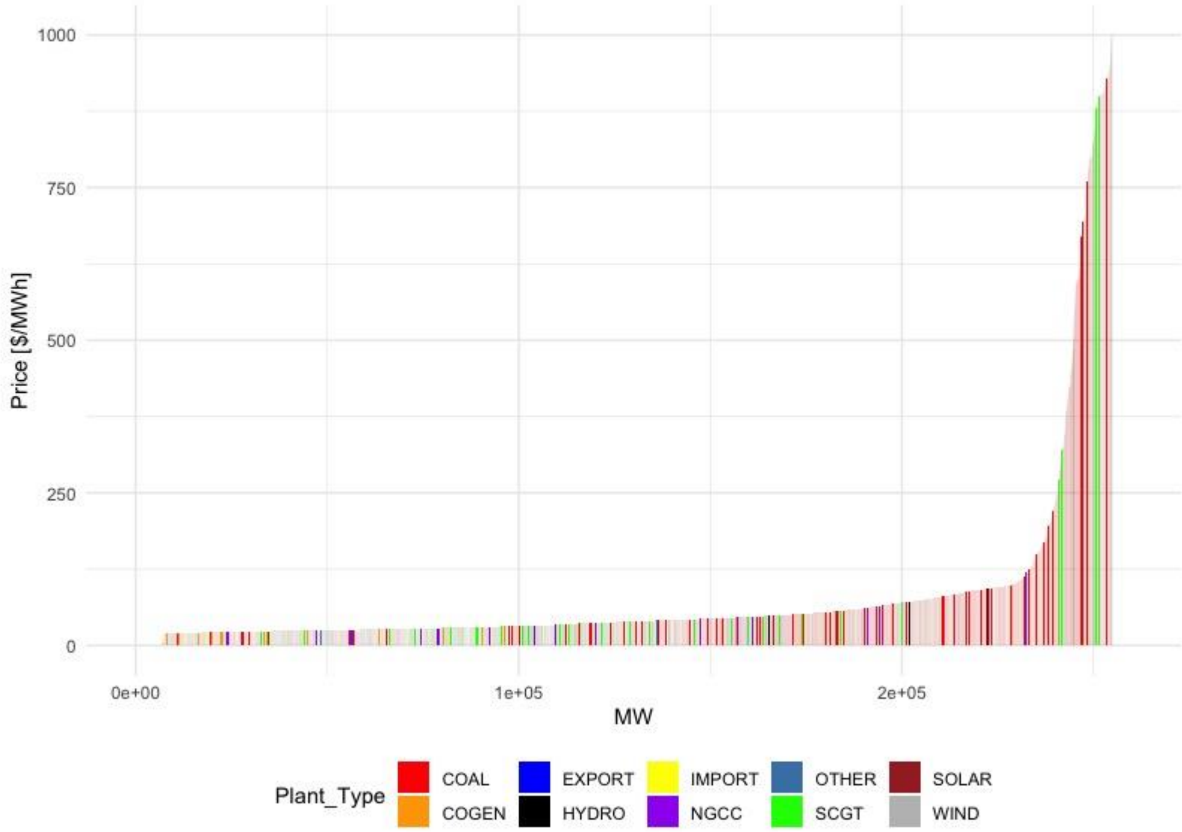

***Figure 8**: Hourly dispatched for 2018*

One can see many representations of each source, meaning that each of them is present on every price (another assumption has been made on $0 price, replaced for $1). This is the representation of the mean of all the hours of 2018, meaning that this curve is not representing a simple hour (Figure 7), but a curve of all year. The last power plants in the chart, bidding at a price close to $1000, are the last power plants offering for each hour, usually at this price cause, in case they get into the system, have a higher profit.

The x-axis shows the mean amount per hour, resulting in the amount of MW per year in total, accumulating MW till all the energy needed is reached.

1.3 PRICE BEHAVIOR

The price is another important factor when talking about behavior difference for each source. In the next charts the price of the market will be seen as a mean result of all the hours of the year per each hour of the day.

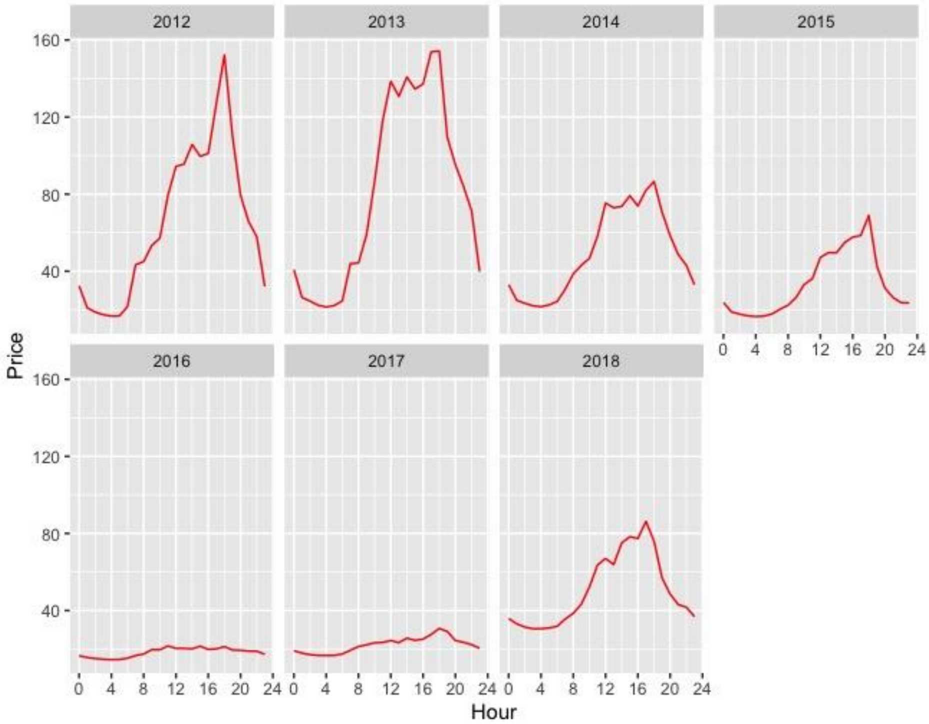

Figure 9*: Pool price mean capture for each year between 2012-2018*

The main reason for the low price of the 2016 and 2017, was the introduction of a new 800 MW NGCC power plant. The behavior of demand can be seen in the following figure:

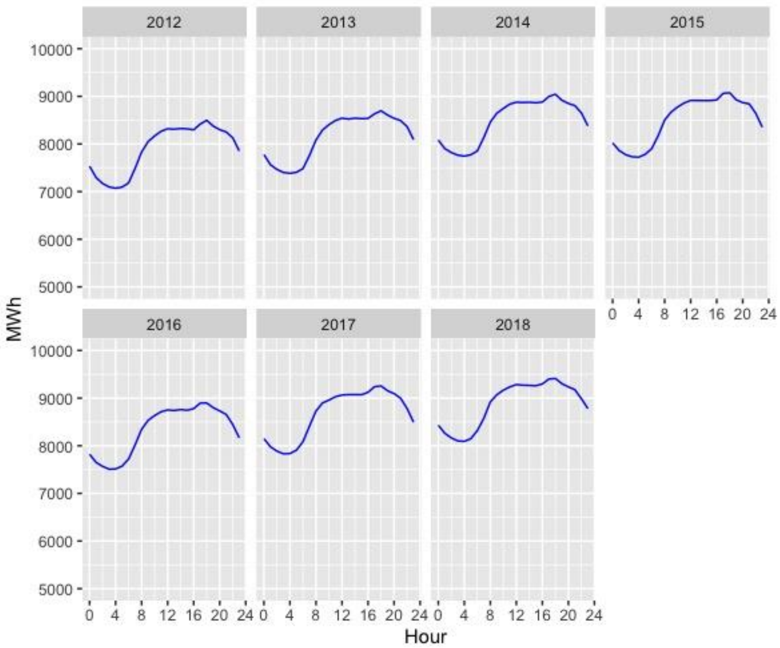

Figure 10*: Mean of Demand of energy per hour*

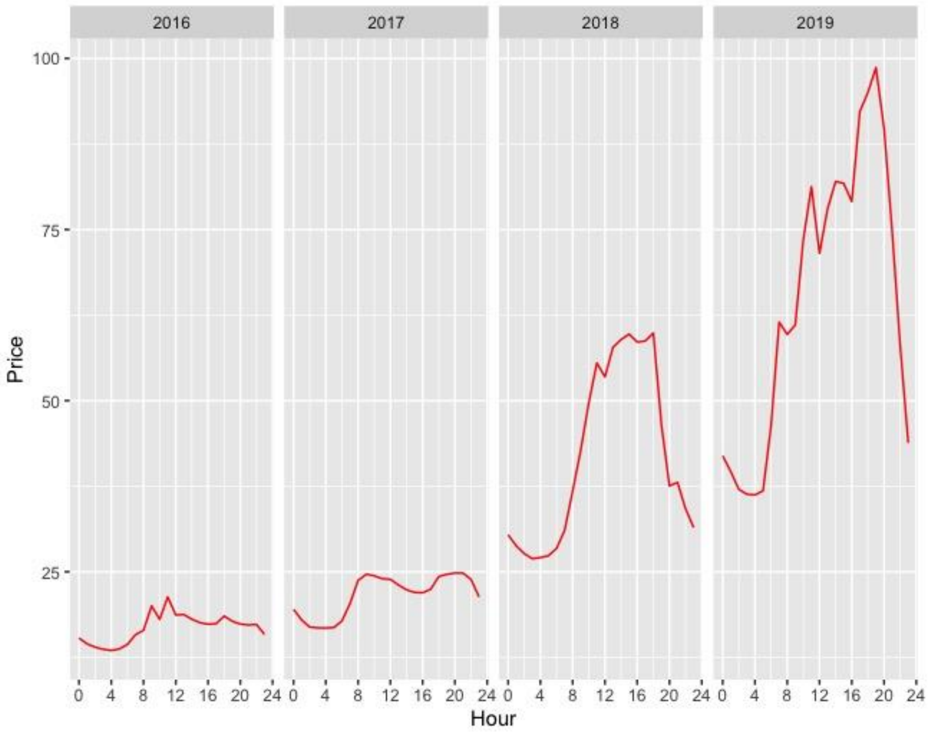

***Figure 11**: Pool price mean capture for Jan-May*

One can see that in 2019, the price is higher compared to earlier years. This can be due to wind generation decrease and will be studied later. In 2019, the pool price is returning to numbers of previous years than 2016. As Albertans had to pay a tax on coal energy, the price per each MWh increased because other power plants that are trying to replace coal are also bidding at a higher price than what bidding coal before was.

Specifically, for 2018, the following chart shows the pool price, where one can observe the difference in each month:

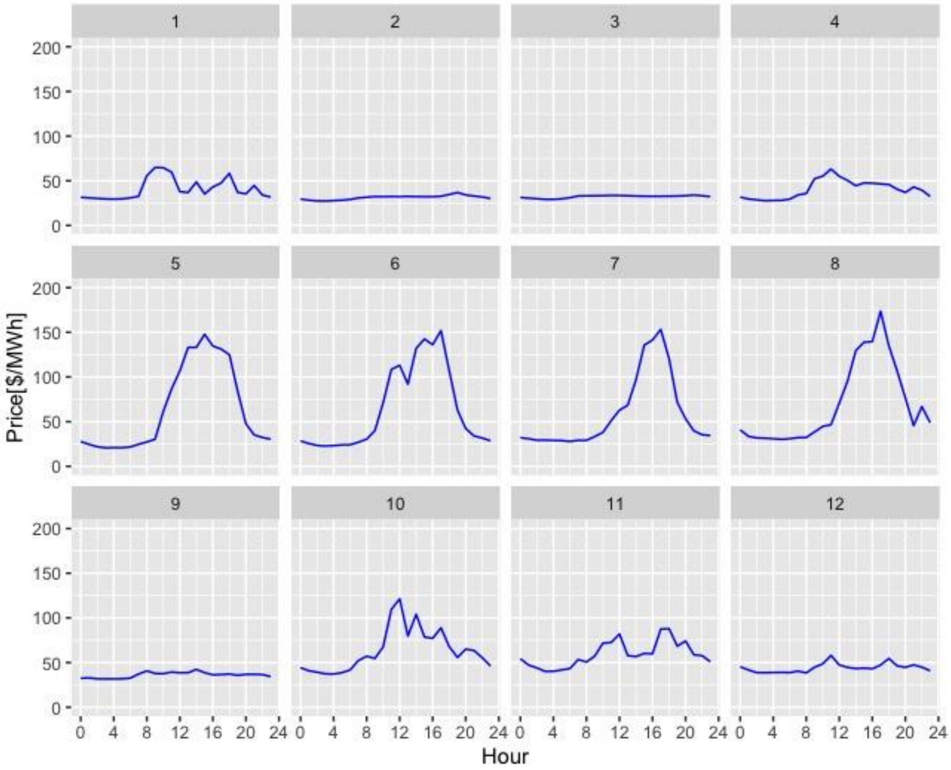

***Figure 12**: Pool price mean capture for each month of 2018*

In Alberta, during winter the demand is usually high, but at the same time there is greater opportunity for electricity generation from wind.

Figure 11 shows the difference in the energy price between summer months and winter months, depending on the energy sources most used, and the energy demanded in that specific periods.

1.4 CO_{2e} EMISSIONS

Next thing to study is the CO2 emissions that is caused by the energy generation, and therefore meaning the amount of CO2 emissions caused by the energy consumption in this province. Only CO2 will be studied, not other pollutant gases like NOx.

In the following chart, one can see the results for the emissions for each type of source of energy generation.

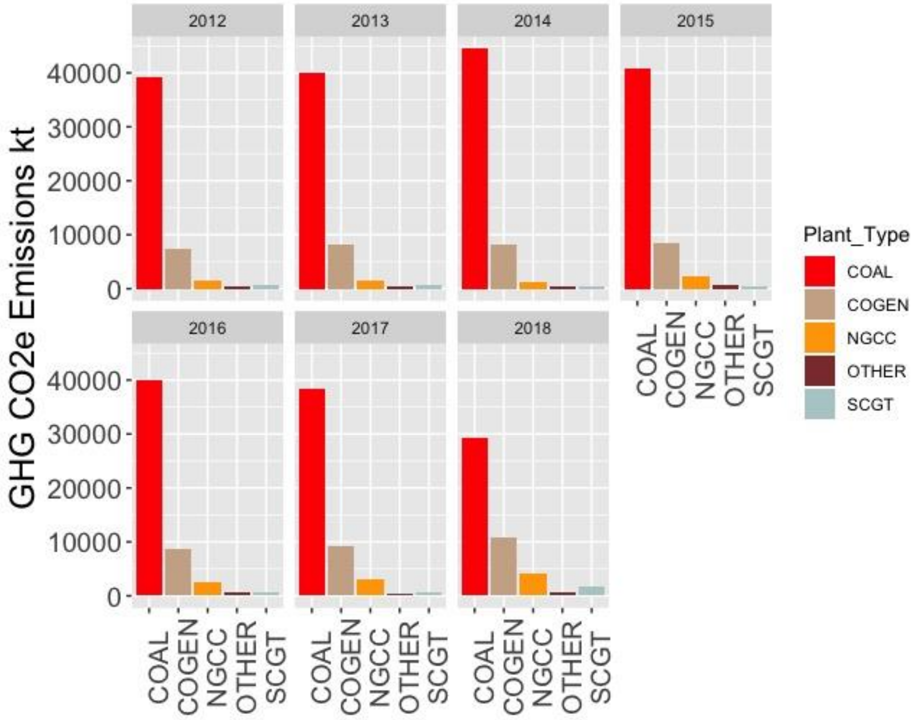

Figure 13: Electrical market emissions per each energy source in ktonnes between 2012-2018

Renewables are not shown because as they are a clean source, the emissions are 0t/MWh. Although other emission factors from the generation process (life cycle) could also be considered, in this paper we are only focusing in the final generation scope.
Coal is the main culprit for pollution as cogeneration is also an important source of energy, being the second that causes more pollution, but really far from coal in terms of pollution. From the results showed in Table 3, coal represents approximately 63.2% of electricity emissions, and cogeneration represents a 23% for 2018.

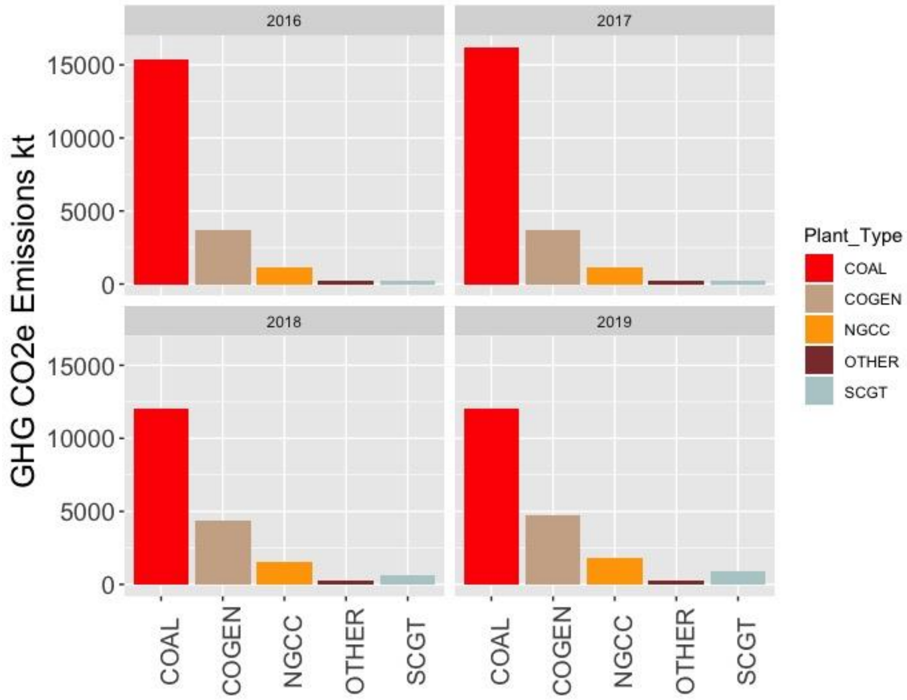

***Figure 14**: Electrical market emissions per each energy source in ktonnes for Jan-May*

In this paper, the emissions of the actual situation will be compared with the hypothetical situation, in which there is no wind contribution, as previously explained. The comparison will be important in order to know how much saving in this province wind is providing.

YEAR / SOURCE	2012			2013			2014		
	Amount	Total	%	Amount	Total	%	Amount	Total	%
COAL	39128	48927	79.9	40108	50664	79.2	44499	54565	81.6
COGEN	7366		15.0	8101		16.0	8177		15.0
NGCC	1486		3.1	1481		3.0	1148		2.1
OTHER	320		0.7	318		0.6	307		0.6
SCGT	627		1.3	656		1.2	434		0.7

***Table 3**: CO_2 emissions 2012-2014*

YEAR / SOURCE	2015			2016			2017			2018		
	Amount	Total	%	Amount	Total	%	Amount	Total	%	Amount	Total	%
COAL	40831	52671	77.5	39891	52396	76.1	38437	51933	74.0	29331	46441	63.2
COGEN	8404		16.0	8775		16.7	9182		17.7	10705		23.0
NGCC	2338		4.4	2584		4.9	3091		5.9	4058		8.7
OTHER	577		1.1	582		1.2	517		1.0	588		1.3
SCGT	521		1.0	564		1.1	706		1.4	1759		3.8

Table 4*: CO_2 emissions 2015-2018*

YEAR / SOURCE	2016			2017			2018			2019		
	Amount	Total	%	Amount	Total	%	Amount	Total	%	Amount	Total	%
COAL	15392	20730	74.3	16214	21516	75.4	12007	18821	63.8	12054	19649	61.3
COGEN	3693		17.8	3713		17.2	4402		23.4	4710		24.0
NGCC	1173		5.7	1172		5.4	1533		8.2	1781		9.1
OTHER	236		1.1	232		1.1	254		1.3	241		1.2
SCGT	236		1.1	185		0.9	625		3.3	863		4.4

Table 5*: CO_2 emissions for Jan-May*

Year	2012	2013	2014	2015	2016	2017	2018	2019*
Total GHGe [kt]	48927	50664	54565	52671	52396	51933	46441	19649
Total GW	69409	71397	74376	74502	73191	75965	77802	32623
Rate [kt/GW]	**0,705**	**0,710**	**0,734**	**0,707**	**0,716**	**0,684**	**0,597**	**0,602**

Table 6*: GHG emission rates (*only available data)*

One can see in table 6 that for 2017 and 2018, the rate of emission per each GW generated is lower than previous years. That means GHG importance in the market is decreasing, cause in this calculation is done considering the variation of energy demand in every year.

On Table 3, 4 and 5, can be seen the importance decreasing of coal in the market cause the emissions are decreasing. Also, the total GHG emissions is decreasing, resulting in an increase of other GHG sources share different than coal.

1.5 RENEWABLE ENERGY

1.5.1 WIND IMPORTANCE IN THE MARKET

Another important thing to analyze is how much energy is generated from wind in recent years, in order to know the situation of wind and its importance in the current market.

Wind is the largest renewable energy technology in the market making up approximately 6% of annual generation as was first seen in Table 2.

Figure 14 shows the wind output as it is very dependent on windy days. These results are the mean of the energy generated from wind of every hour of each of the studying years.

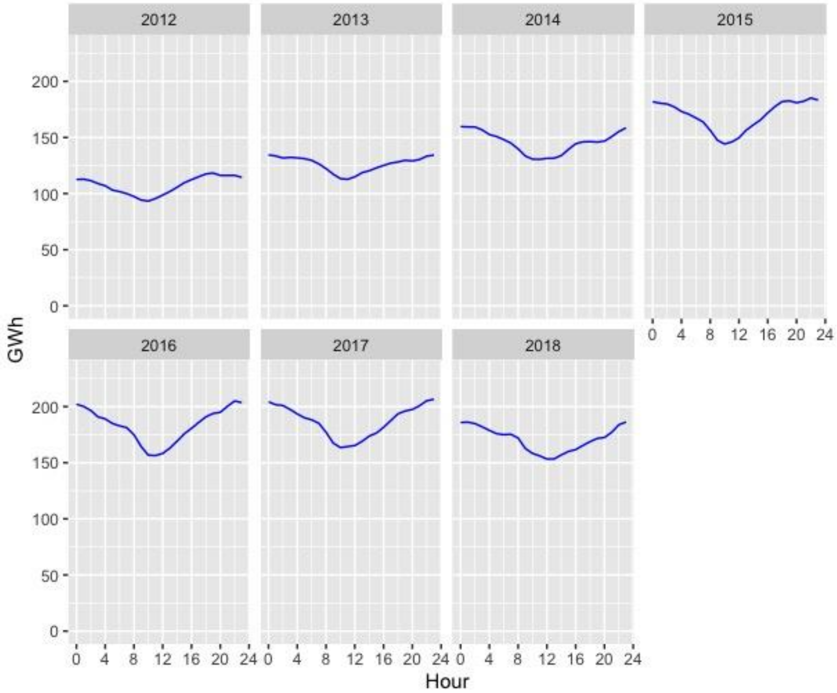

Figure 15: *Alberta's total wind energy generation in GWh per each year between 2012-2018*

The Alberta wind fleet grew from approximately 1088MW in 2012 to 1450 in 2014-2018 and grew again to 1781 MW in 2019. While the daily patters are similar, the average output varies from year to year as can be seen in Figure 14.

Alberta is experiencing a lot of changes in regulation depending on the political party in power, but some laws have been made to remove coal plants in the upcoming years. Trying to replace that amount of GWh/year, approximately 30000 GWh in 2018, will require an investment in renewable energy in order to secure that this replacement is made with renewable energy.

The following table shows the amount of energy that wind is generating in the system. For 2019, in this case wind data is available not only till May but August.

Year/ Month	2012	2013	2014	2015	2016	2017	2018	2019
January	325.4	380.9	381.3	496.9	410.9	431.0	519.4	469.5
February	218.1	345.3	217.0	295.9	491.0	304.5	353.4	174.7
March	261.7	223.9	219.2	471.4	444.5	418.3	267.0	262.8
April	186.0	264.7	290.5	372.0	339.9	355.8	313.6	367.7
May	199.4	230.3	210.0	223.2	298.0	347.9	297.5	201.7
June	215.6	189.3	240.8	162.5	372.1	365.9	342.4	N/A
July	128.0	119.8	222.5	234.2	225.2	252.9	216.5	N/A
August	124.7	125.7	172.8	251.5	230.3	222.9	260.7	N/A
September	171.0.	222.7	278.1	326.3	359.2	294.9	189.8	N/A
October	212.6	273.5	460.5	392.4	302.4	540.8	359.7	N/A
November	246.2	319.3	351.3	416.6	475.2	497.9	456.5	N/A
December	291.4	334.5	452.0	424.5	452.3	453.7	526.7	N/A
Capacity Factor	32%	32%	24%	32%	35%	35%	32%	N/A

***Table 7**: Wind energy amount in GW for each month of every year*

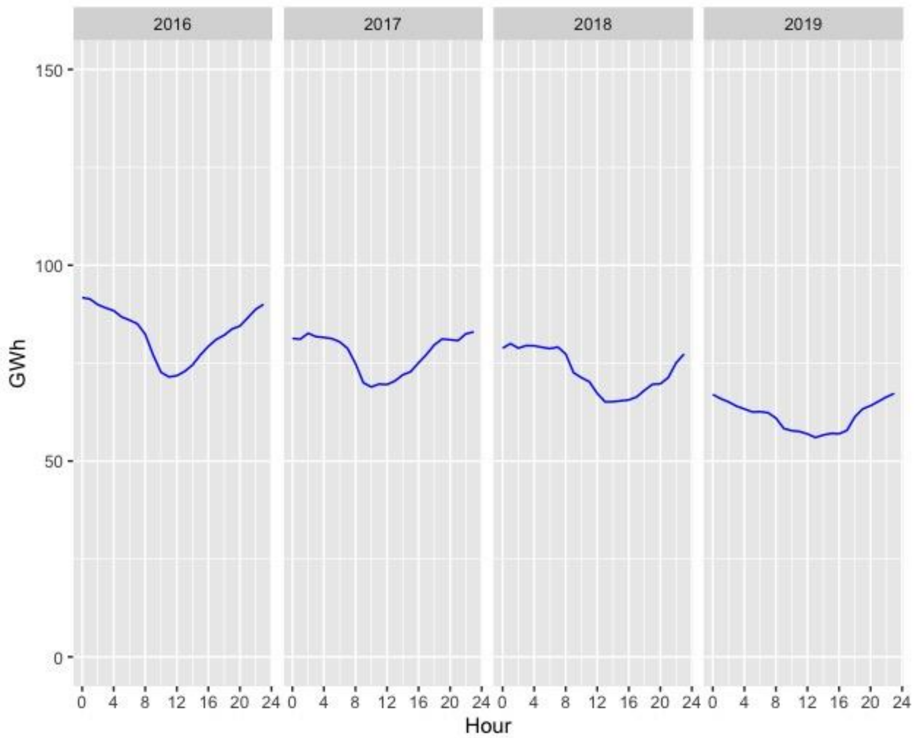

***Figure 16**: Wind energy generation in GWh for Jan-May*

In Table 7, one can check that winter months are windier than summer months, affecting on the energy generation coming from renewable energy in those periods.

Wind power plants are mainly in the south of the province, where the wind is more prevalent and allows greater energy generation. Most of the wind plants were built there because the wind is more intense in that area.

2. WIND DISPLACEMENT IN THE MARKET

In this chapter we will introduce and go forward on the main goal of this paper, that is none other than examine the effects of wind energy on the market dispatch and how that effects both prices and emissions. Also tries to examine the counter-facts if wind was not present in the market in the actual market situation studied previously.

In order to do that, we remove the energy generation by wind of every hour of the studied years and replace it with the next available bids from the historic market data.

Is unknown whether those power plants are going to be able to generate the energy at the same price or if the bidding energy order will still be the same if wind it's not a feasible option. One can assume that the power plants that were bidding next in the market would still be offering at the same price, even if they knew wind was not there. The price will be assumed to be the same as in the actual data from AESO.

This counter-factual scenario is predicated on the assumption that power plants that were not dispatched into the market would have bid the same in the absence of wind energy being available. While this is a reasonable assumption for short-term bids, it is not how the market would have evolved different is they knew MW of wind were never built. The short-term impacts of large amounts of wind generation can be tested by comparing windy vs non-windy days.

2.1 NEW DISPATCHED RESULTS

To move forward, we subtract the wind amount generation and replace it with those immediate plants that were not dispatched in the market, resulting in an increase of the energy amount generated for each type of energy compared to the actual situation showed in Figure 5.

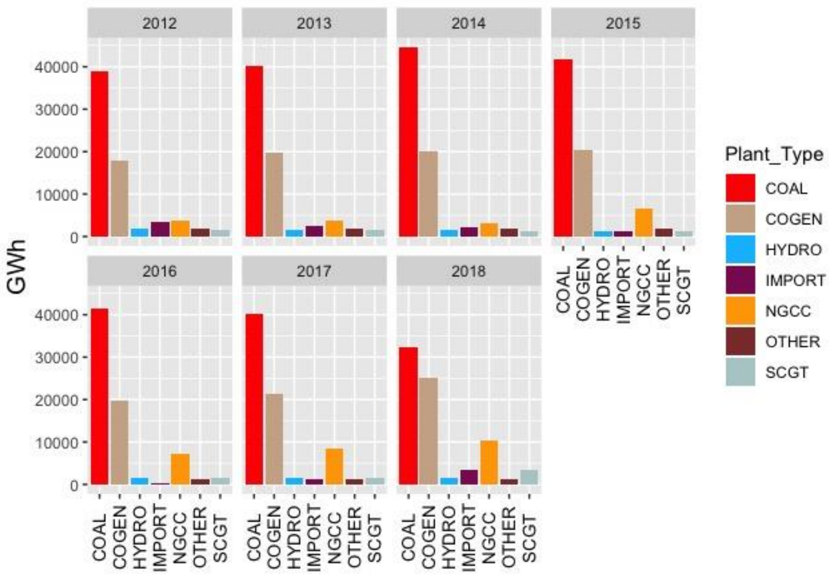

Figure 17: *GWh energy dispatched for no-wind scenario between 2012-2018*

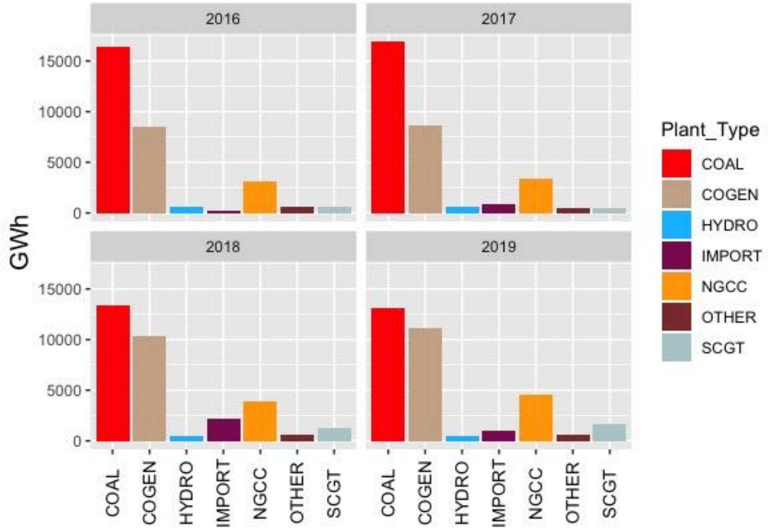

***Figure 18**: GWh energy dispatched for no-wind scenario for Jan-May*

To observe the effects of the introduction of wind energy in the electrical market, one can calculate this new generation as the savings of other types of energy dispatched.

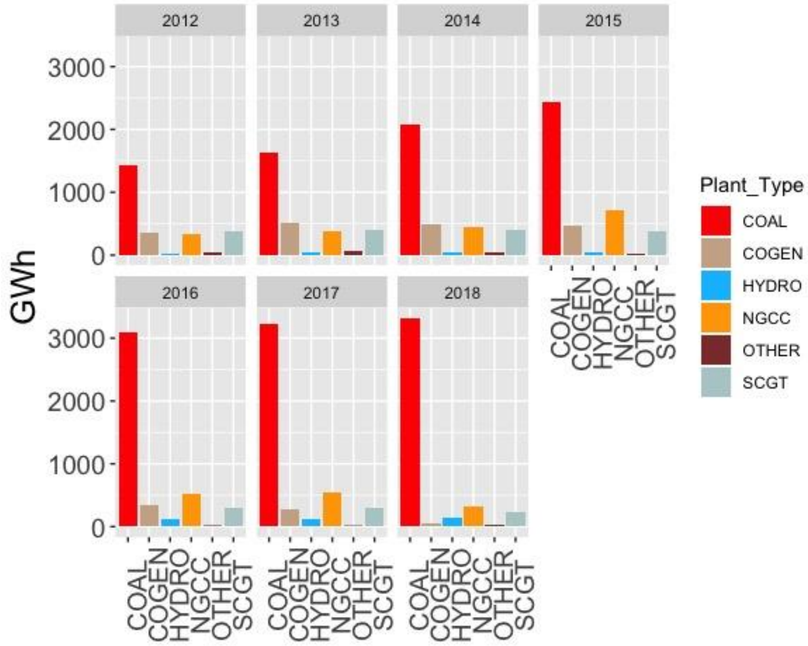

***Figure 19**: GWh savings amount dispatched between 2012-2018*

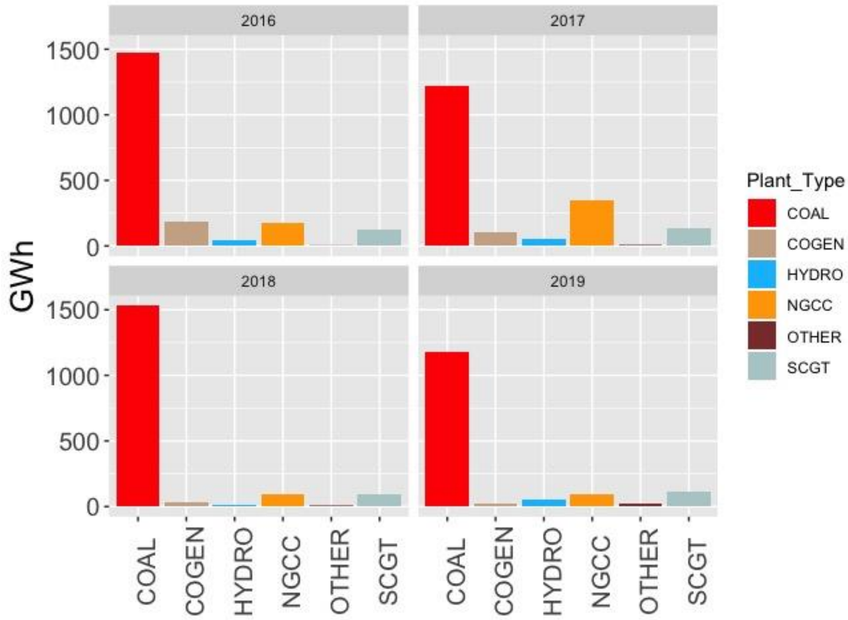

Figure 20: *GWh savings amount dispatched for Jan-May*

Figures 18 and 19 only represent the amount dispatched due to the power plants that were not in the market before but now are.

As seen in these figures, the introduction of wind energy resulted in significant savings in the amount of coal in the market, resulting in lower emissions.

All these data showed in the different charts above, can be summarized in the next tables:

Year / Source	2012				2013				2014			
	Act.	CFS	Diff.	% Inc.	Act.	CFS	Diff.	% Inc.	Act.	CFS	Diff.	% Inc.
COAL	37624	39045	1421	3.78	38511	40134	1623	4.21	42518	44592	2074	4.88
COGEN	17453	17816	363	2.08	19298	19800	502	2.60	19518	20010	492	2.52
HYDRO	1786	1814	28	1.57	1612	1651	39	2.42	1511	1548	37	2.45
IMPORT	3575	3575	0	0.03	2542	2542	0	0.00	2062	2062	0	0.00
NGCC	3348	3689	341	10.19	3316	3690	374	11.28	2603	3053	450	17.29
OTHER	1900	1938	38	2.00	1902	1962	60	3.15	1872	1905	33	1.76
SCGT	1143	1519	376	32.90	1184	1579	395	33.36	795	1196	401	50.44

Table 8: *Comparison between actual situation and counter fact no-wind scenario in ktonnes*

Year / Source	2015				2016				2017			
	Act.	CFS	Diff.	% Inc.	Act.	CFS	Diff.	% Inc.	Act.	CFS	Diff.	% Inc.
COAL	39275	41710	2435	6.20	38484	41485	3001	7.80	37223	40332	3109	8.35
COGEN	19944	20415	471	2.36	19539	19891	352	1.80	21077	21383	306	1.45
HYDRO	1307	1348	41	3.14	1348	1489	141	10.46	1487	1611	124	8.34
IMPORT	1093	1093	0	0.00	435	435	0	0.00	1297	1297	0	0.00
NGCC	5844	6548	704	12.05	6577	7127	550	8.36	7887	8473	586	7.43
OTHER	1998	2014	16	0.80	1339	1353	14	1.05	1195	1206	11	0.92
SCGT	973	1363	390	40.08	1067	1400	333	31.21	1313	1642	329	25.06

***Table 9**: Comparison between actual situation and counter fact no-wind scenario in ktonnes*

Year / Source	2018				2019*			
	Act.	CFS	Diff.	% Inc.	Act.	CFS	Diff.	% Inc.
COAL	28999	32278	3279	11.31	11975	13148	1173	9.80
COGEN	25081	25140	59	0.24	11166	11185	19	0.17
HYDRO	1452	1610	158	10.88	416	468	52	12.50
IMPORT	3400	3400	0	0.00	980	980	0	0.00
NGCC	10156	10481	325	3.20	4443	4537	94	2.12
OTHER	1344	1378	34	2.53	564	584	20	3.55
SCGT	3244	3488	244	7.52	1594	1713	119	7.47

***Table 10**: Comparison between actual situation and counter fact no-wind scenario in ktonnes (*only available data)*

The following table shows the share that the savings represent compared to what has been generated per each energy source in the actual data.

Year / Source	2012	2013	2014	2015	2016	2017	2018	2019*
COAL	3.8	4.2	4.9	6.2	7.9	8.5	11.5	9.9
COGEN	2.1	2.6	2.5	2.4	1.8	1.5	0.3	0.2
HYDRO	1.6	2.4	2.4	3.2	10.5	8.5	11.0	12.3
NGCC	10.21	11.3	17.3	12.1	8.4	7.5	3.2	2.1
OTHER	2.0	3.1	1.8	0.8	1.1	1.0	2.5	3.6
SCGT	33.0	33.4	50.4	40.2	31.3	25.1	7.5	7.3

***Table 11**: Share in % of savings compared to actual generation per source (*only available data)*

From Table 11 one can see that there is a lot of hydro generation that is not used because it has limited reservoir capacity in Alberta and is often used as peaking supply. Because of this limited capacity, hydro can only supply a maximum amount, overestimating hydro cause it can only be used once and is represented more times.

But every hour and therefore every year has a different amount of wind generation. The results can be represented in a normalized way so one can compare the years between them. That is the result of the total dispatched energy per source in a year divided per the total amount of wind generation of that year. This is represented in Figures 20 and 21:

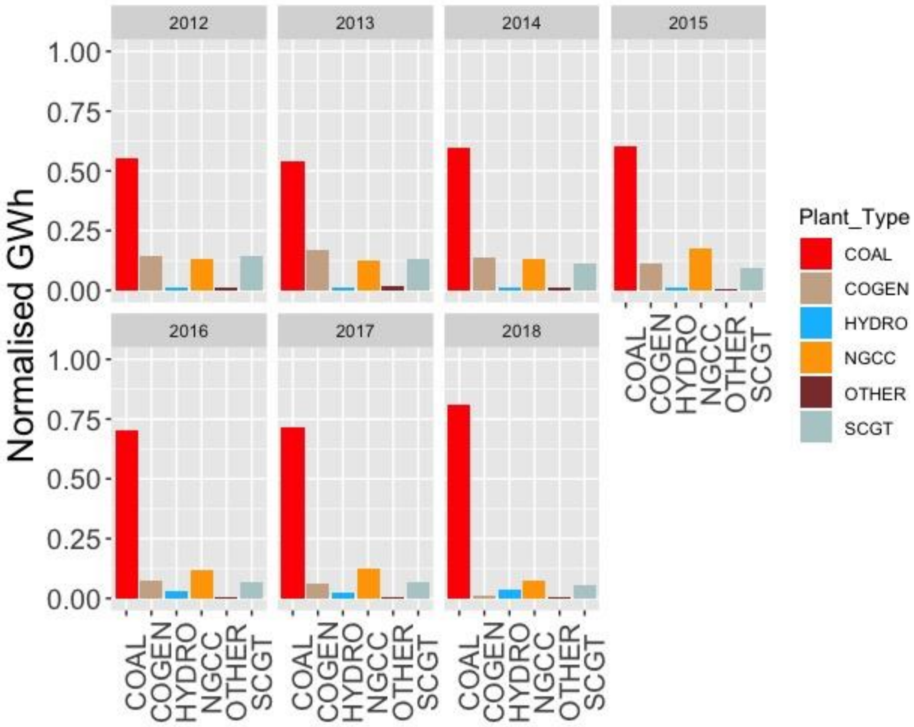

***Figure 21**: GWh energy dispatched per energy source normalized for no-wind scenario between 2012-2018*

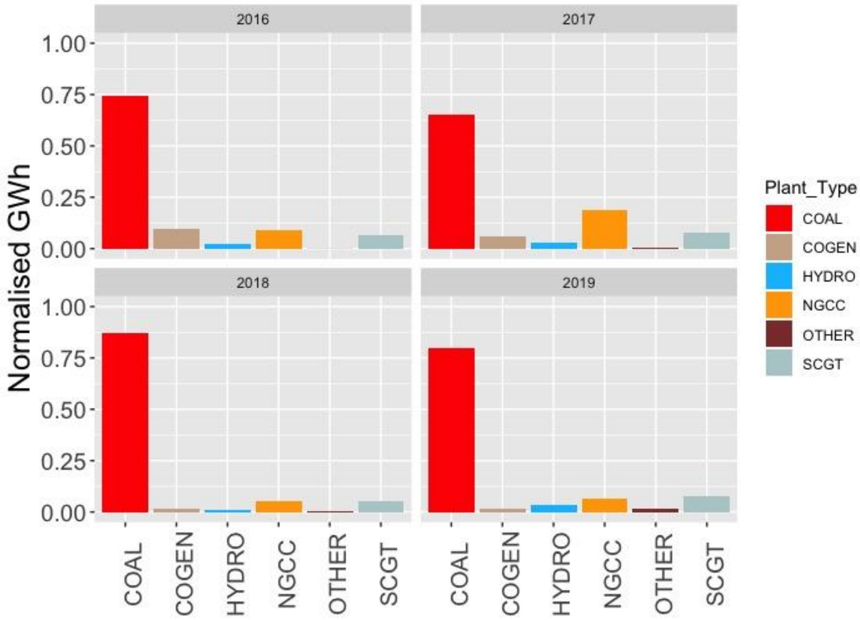

Figure 22: *GWh energy dispatched per energy source normalized for no-wind scenario for Jan-May*

Here it is possible to see how much energy wind is saving for each type of energy source. Coal is the main source that is displaced from the market because of wind, despite the fact that is already the source of 50% of Alberta's electricity generation. Considering the results shown in Table 10, in 2018 coal would have represented 42% (no-wind scenario data) of electricity generation instead of the 37% (actual data) seen in Table 1.

With the normalized chart, coal represented more than half of the energy needed to replace wind in every year, and in 2018 that number rose to more than 75%.

Figure 21 allows one to see that on winter months, Jan-May, wind is mainly displacing coal from the system for all 4 years shown.

2.2 NEW PRICE BEHAVIOR

As seen in the previous chapter, if wind is not an available resource, then most of the energy to fill demand comes from coal. This will affect the price, as wind bids at $0/MWh in Alberta's market.

In this chapter the focus will be on how the pool price by removing zero-bidding technology is affected and compare this to the pool price seen before in Figure 9. A huge rise in the price per hour is expected as wind energy bidding at $0 has been removed.

The following figure represents the no-wind scenario pool price (red) compared to the actual pool price (green):

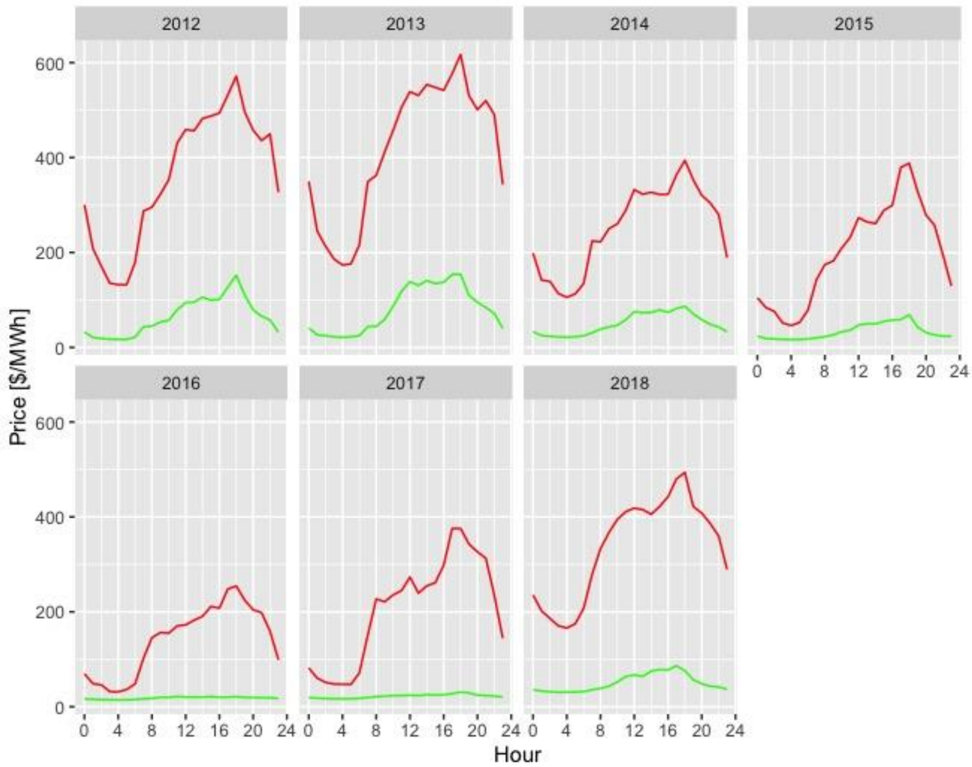

Figure 23: *Comparison between two pool prices: actual data and wind bids removed between 2012-2018*

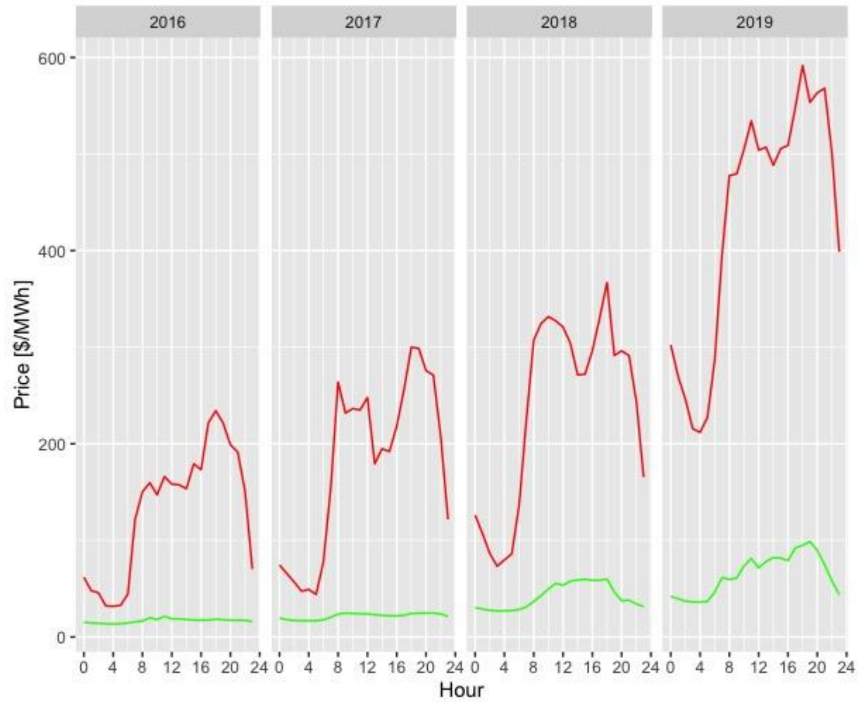

***Figure 24**: Comparison between two pool prices: actual data and wind bids removed for Jan-May*

As seen, the price is much higher compared to the actual pool price. This is due to the extraction of wind energy and replacement with those power plants that were next in the queue. Here, it must be said that the assumption made at the beginning considering the same price as in the actual data may lead to an error. This is because coal plants, when they know that in a specific hour they will not be in the market, they offer the energy at a really high price just in case it is necessary to go in at the last minute. This can affect the results, but as mentioned, it is assumed they would be still offering at the same price.

Now, so we can really study if the difference is correct, these results must be compared with those hours of days in which wind was not an important source. Those hours in the actual data that could be considered as no windy hours. In order to do so, a sample of hours that can represent this problem as accurately as possible must be selected. In the period of study there is a total of 67145 hours, and a sample of 10% of the hours would be close to the results desired. To select only 10% of the hours, we must cut the selection of those hours that have less than 40 MW from wind. So now, one can see how the pool price behavior of those hours is and compare it to this new hypothetical situation which are definitely no windy hours. These two situations are compared because they should be similar as wind is not an important source in either of them.

To do this, the focus remains only on those hours that have less than 40 MW. The following chart represents the mean pool price of those hours.

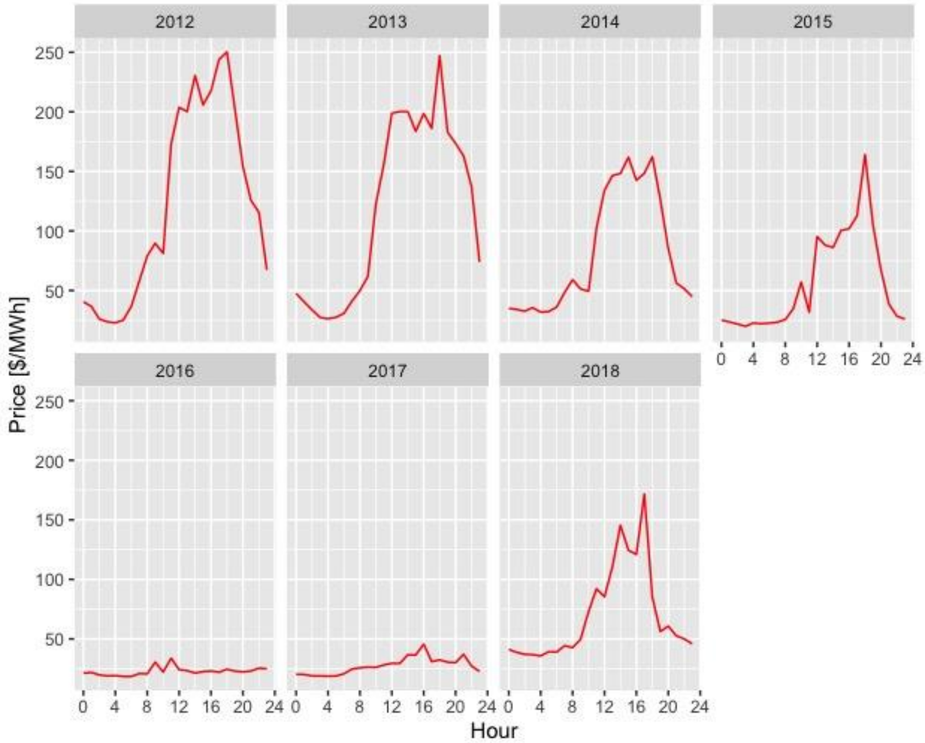

***Figure 25**: Pool price for actual data hours with less than 40 MW between 2012-2018*

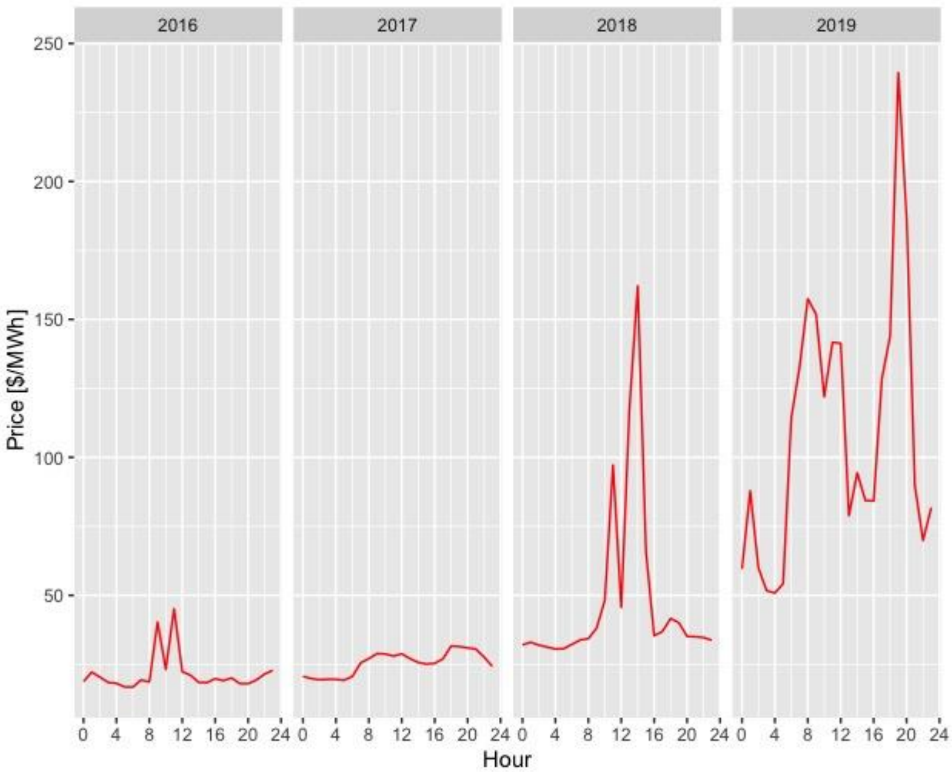

***Figure 26**: Pool price for actual data hours with less than 40 MW for Jan-May*

In 2016 and 2017 the price remains low even if wind was not important those hours, but as mentioned, those years the demand was not high.

Now one can compare the three pool price charts in order to see if the difference in the price is significant or not between actual data (green), wind removed scenario (red) and less than 40 MW of wind (blue).

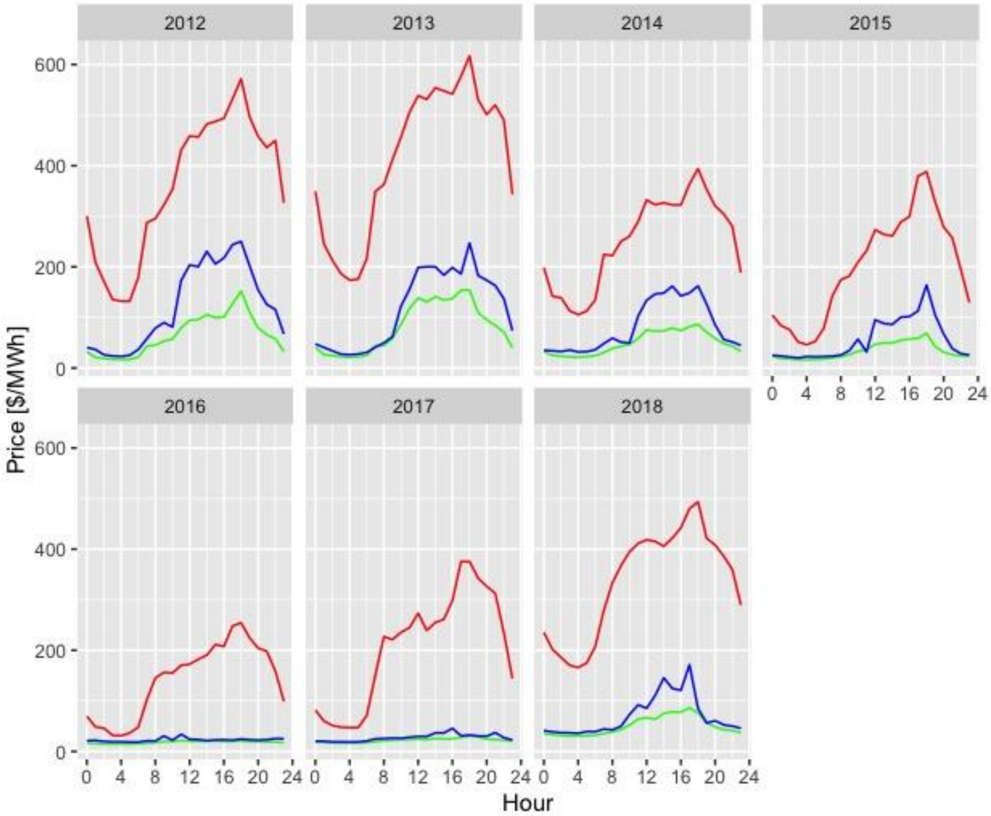

Figure 27*: Comparison between three pool prices: actual data, no wind and less than 40 MW between 2012-2018*

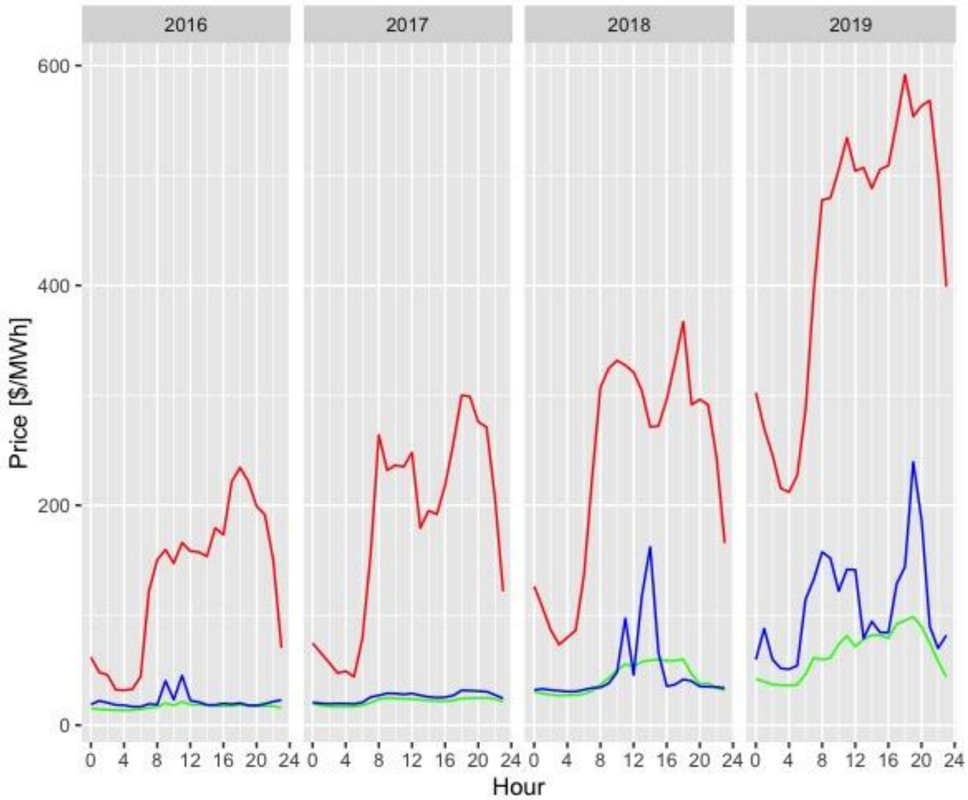

***Figure 28**: Comparison between three pool prices: actual data, no wind and less than 40 MW for Jan-May*

The results show that in this new situation being tried, the price is much higher than those days considered as no windy. If the pool price is significantly different, there has to be some explanation. This indicates that market bids are clearly impacted by participants knowing whether or not will be windy. As mentioned, although coal plants also bid at $0/MWh, they bid at higher prices and that is not realistic in this no-wind scenario, because they could be bidding at different prices if wind is not there. Also, the assumption made that the power plants keep the same order as the actual data is unknown, although we can assume that would be really similar to no-wind hours.

This, indeed, is something to keep studying in the near future, as it is a potential work to solve and check if the power plants order is right. Some work can be carried out in this field for future people interested.

2.3 GHG EMISSIONS RESULTS

With all the previous results explained, another issue of this paper must be focused on the emissions savings that the introduction of wind in the electrical market is giving.

In order to do so, we must pull apart those power plants that are not in the market and study them separately. The results for the new electrical market emissions situation is represented in figure 28:

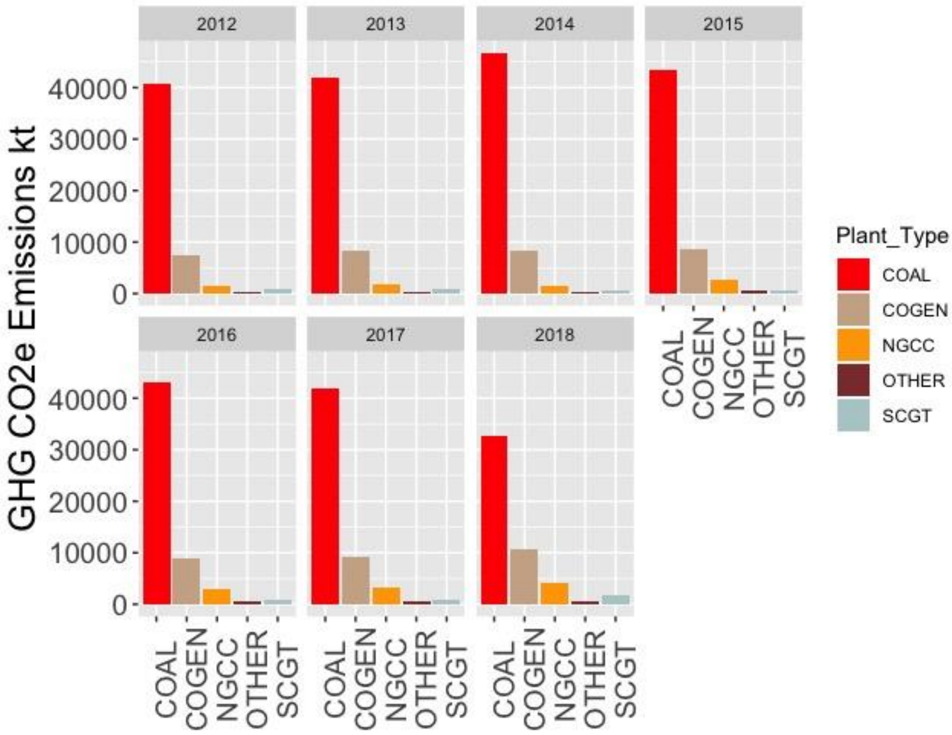

Figure 29*: Electrical market emissions with wind bidding removed in ktonnes between 2012-2018*

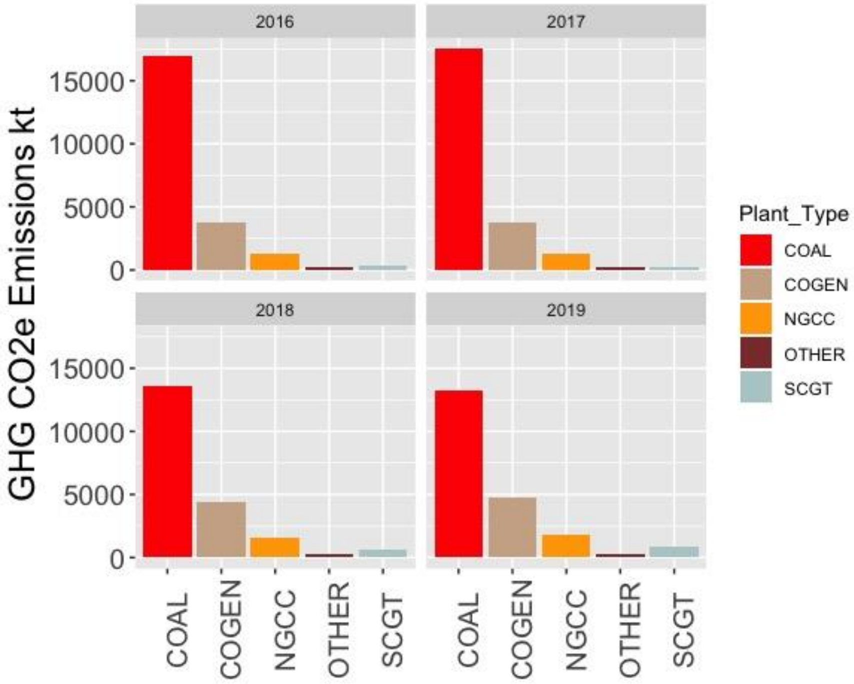

***Figure 30**: New electrical market emissions with no wind in ktonnes for Jan-May*

Figures above represent the no-wind scenario emissions, and in the following figures one can see the increasing between both situations. This increasing is actually the savings that wind is causing in the market.

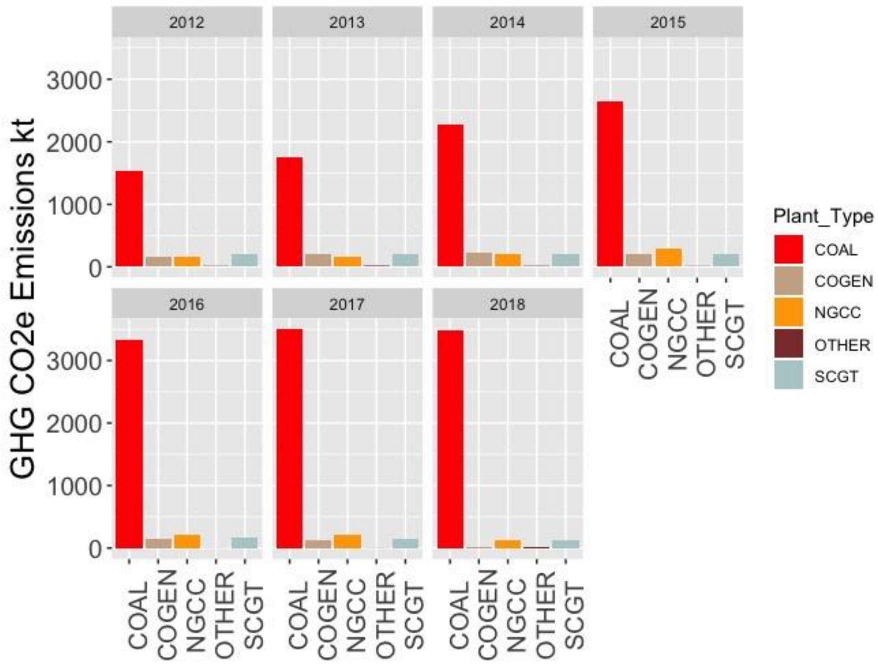

***Figure 31**: Electrical market wind emissions savings in ktonnes for 2012-2018*

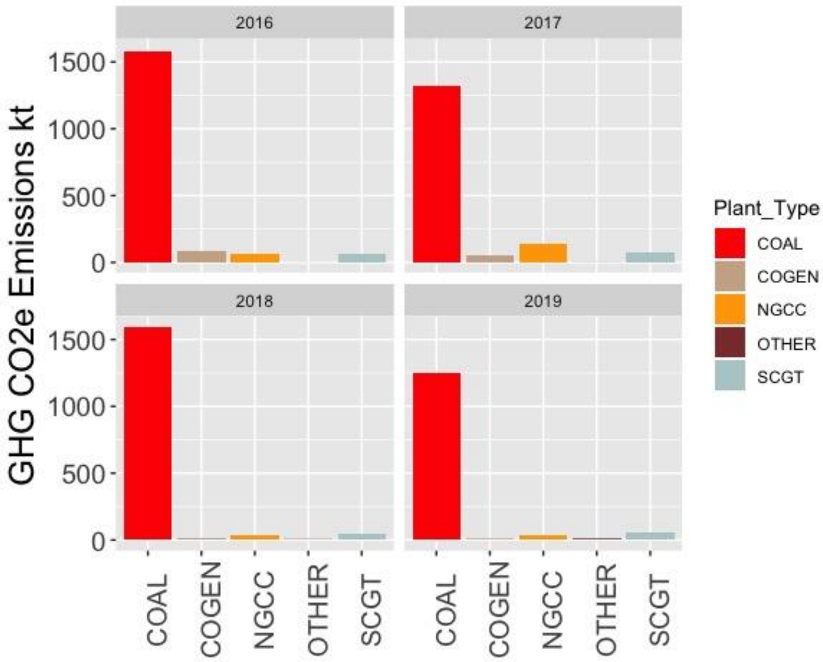

***Figure 32**: Electrical market wind emissions savings in ktonnes for Jan-May*

The emissions that wind is saving from being introduced to the market are mainly coming from coal as we can see in the figure above and mentioned before. The share of coal that wind is saving per each year can be seen in the following table:

Year/ Source	2012	2013	2014	2015	2016	2017	2018	2019*
COAL	74.8	74.4	78.1	79.0	86.6	87.4	92.6	91.6

***Table 12**: Share of coal in wind emissions savings (%) (*only available data)*

Coal share on the wind emissions savings, shows us that wind is basically displacing coal from the market and therefore, decreasing the amount of ktonnes of emissions that coal would be emitting in a no-wind scenario.

3. CONCLUSIONS

This paper has been useful to see the importance that coal currently has, and how important would it be if wind was not an available resource in Alberta.

As Canada has 67% of renewable sources and more or less a 20% of GHG sources, Alberta is on the opposite path. We have seen that in recent years, coal represents almost 40% followed by cogeneration and natural gas with 35% and 15%. The renewables are keeping around 7-8%, much lower than the Canada average.

The charts seen have shown that if wind was not present, Alberta's electrical market would have increased its share of coal.

As mentioned throughout this paper, the assumptions made were the only way to go ahead on the analysis, but to check if these assumptions could be done in a better way is a source of potential work for the future. It is interesting to know what the behavior of the private business could be when wind is in the market and when it is not, and at the same time study the interest of these companies in order to predict as accurately as possible their future moves.

The reason why this paper is important, is because we are moving to a more sustainable society and one of the paths to follow is investment in renewable source. If we can prove, as we have done in this paper, that renewables are contributing to that goal and at the same time allow people to reduce their electricity bills, then is something important to share to the world for future movements.

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