Provincial Allocations of Canada's 2030 INDC and a 2-Degree Scenario Target Using a Multi-Criteria Weighted Sum Model

ENVS 4902 Environmental Science Undergraduate Thesis

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Table of Contents

Abstract

At the 2015 COP21 Paris Agreement, Canada restated its commitment to a 2030 target of a 30% reduction from 2005 level emissions as an Intended Nationally Determined Contribution (INDC). At this agreement, nations in attendance submitted INDC's with the goal of limiting global temperature increase to 2 degrees above pre-industrial times, and a further goal of limiting warming to 1.5 degrees (Government of Canada, 2016). However, even if every nation reaches their INDC target the global temperature increase will still far exceed the 2-degree target (UNEP, 2017). In recent history, it has been the provinces that have taken the first steps towards action against climate change. Despite this, provincial "goals"[1] in aggregate will fall short of Canada's 2030 INDC (Boothe and Boudreault, 2016a). The objective of this paper is to use multiple burden sharing rules to allocate reduction targets which cumulatively meet Canada's 2030 INDC as well as a 2-degree 'fair share' target. The burden sharing rules of grandfathering, efficiency, and ability to pay are incorporated into a multi-criterion based weighted sum distribution model and the implication of their weightings are examined through a sensitivity analysis. The role of Alberta in meeting Canada's INDC is explored by comparing the average required reduction allocated per province when Alberta is a part of the model's allocations and when Alberta's reductions are equal to their provincial goal. The allocations given under this model were shown to have several desirable qualities, and the results may be used to help guide further research into the use of burden sharing rules in assigning provincial reduction targets or allocations for a cap and trade program.

Key Words: Emissions Allocations, Climate Policy, Burden Sharing, Multi-Criteria Decision Analysis

Introduction

With the recognition of deep emissions cuts required to avoid the devastating consequences of climate change comes a quota on allowable future emissions (UNEP, 2017). Deciding how to allocate this limited emission space has been a topic of controversy at the international level with considerations of differing responsibilities for emissions reductions between nations. This challenge also exists at the subnational levels with the allocation of national emissions quotas and reduction targets at the state and firm level. The consequences of climate change, recently the extreme precipitation events during Hurricane Harvey which left 80 dead and 100,000 homeless, are already being experienced and will worsen as temperatures continue to rise (van Oldenborgh, 2017). The likelihood that these consequences can be avoided will be largely dependent on the successful assignment of emissions allocations which correspond to the limiting of increasing global temperature.

Past climate agreements

There have been multiple attempts to unify the major CO_2 emitting nations under a single climate agreement but for the most part they have consistently fallen short of their targets and goals. The first international climate agreement was made in 1992 at the Earth Summit in Rio de Janeiro. The most important development from this agreement was the goal to achieve "the stabilization of greenhouse gas concentrations which would prevent dangerous anthropogenic interference with the climate system", although no level was formally defined as "dangerous" (UNFCCC, 1992). The 1997 Kyoto Protocol set targets for Annex I nations to reduce their emissions below 1990 levels by 5% by 2012 (United Nations, 2018). There are currently 192

parties to the Kyoto Protocol although the United States never ratified the deal and Canada later backed out (United Nations, 2018). With the Kyoto protocol deadline almost up and many targets unachieved, a second round of negotiations took place setting the stage for the Doha Amendment. The amendment sought to renew targets with the goal of reducing emissions by at least 18% below 1990 levels by 2020 but has yet to be put into force with 95 of the required 144 parties having submitted their "instruments of acceptance" (Nelson, 2017). In 2009 the Copenhagen Accord, which accounted for all major economies, was signed recognizing climate change as one of the greatest challenges of our time and emphasizing the importance of collective political action to combat climate change (UNFCCC, 2014). The agreement was not legally binding (UNFCCC, 2014). The most recent climate agreement was the 2015 COP 21 Paris agreement which introduced Intended Nationally Determined Contributions (INDC's) (United Nations, 2017). An INDC allows for a nation to set their own targets with the goal of keeping warming under 2 degrees and a further goal of limiting warming to 1.5 degrees Celsius (United Nations, 2017). The target of limiting global temperature increase to 2 degrees Celsius above industrial levels was first recognized politically in 1996 by the European Council of environment ministers (European Commission, 1996). This target originated in a paper by economist W.D. Nordhaus in 1975 as a requirement to keep within "the normal range of climatic variation" (Jaeger & Jaeger, 2008). It was later argued that temperature increases beyond the 2-degree limit placed many ecosystems are at risk (Lang, Leuenberger & Schwaneder, 1999). To date 170 countries of the 197 signatories have ratified the Paris agreement (United Nations, 2017).

The International Emissions Gap

If each nation successfully follows through with their INDC, warming will not be kept below 2 degrees but will rather be closer to 3.4 degrees of warming (Climate Action Tracker, 2017). The discrepancy between the cumulative emissions reductions and what is needed to reach the 2 and 1.5-degree targets is referred to as "the emissions gap" (UNEP, 2017). As of 2017, the combined total of all nations' INDCs will cumulatively use up 80% of the 2-degree carbon budget by 2030 and deplete the entirety of the 1.5-degree carbon budget (UNEP, 2017). Because of this, the Paris Agreement relies on nations reaffirming and updating their INDC's with more ambitious reduction goals to keep global temperature increase below 2 degrees (United Nations, 2017). It has been suggested that to reach the 2-degree goal and a further target of 1.5 degrees global emissions must peak by 2020 (UNEP, 2017). Overall the G20's progress towards meeting their 2020 goals is behind where it needs to be, making the challenge of reaching their 2030 targets more difficult (UNEP, 2017). Current international commitments are not adequate in meeting the UNFCCC 2 degree and 1.5 degree targets and as such, more aggressive reduction targets will need to be set to avoid dangerous levels of climate change.

Canada's 2030 INDC & the National Emissions Gap

For the COP 21 Paris agreement, Canada has set a goal of reducing emissions by 30% below 2005 levels and a corresponding emissions target of 523 $MtCO_2e$ (Climate Action Tracker, 2017). To achieve this goal Canada is planning on using international mechanisms in the form of international credits as well as net emissions from land use, land use change and forestry (LULUCF) (Government of Canada, 2017). While approaches to LULUCF emissions are still being "examined", Canada has stated that it intends to exclude emissions from natural disturbances from its LULUCF accounting (Government of Canada, 2017). LULUCF emissions are often

accounted for separately from regular emissions due to the associated levels of uncertainty in accounting caused by inter-seasonal variations (UNEP, 2017). Grassi et al. (2017) found large variations between cumulative country LULUCF reports and scientific reports (such as IPCC reports) which may be in part due to the difference of consideration of what does and what does not qualify as a carbon sink. According to a 2017 analysis by Environment and Climate Change Canada, using policies and measures put in place as of November 1st, 2016, Canada is on track to reach between 720-731 $MtCO_2e$ by 2020 and between 697-742 $MtCO_2e$ for 2030 excluding LULUCF (Environment and Climate Change Canada, 2017). These projections greatly exceed Canada's 2020 target of 622 $MtCO_2e$ and the 2030 target of 523 $MtCO_2e$ excluding LULUCF (Government of Canada, 2016). A 2016 analysis on Canada's provincial GHG emissions goals by Boothe and Boudreault concluded that if each province meets their proposed goals the cumulative reduction will miss the 2030 INDC by 55 $MtCO_2$[2] (Boothe & Boudreault, 2016b). Canada is set to miss their UNFCCC climate targets by a wide margin, targets which were established on the premise of being later updated with stronger levels of ambition.

Canada's 'Fair Share'

Independent modelling and evaluations of nations' INDCs and their progress toward them by the Climate Action Tracker (CAT) in partnership with Climate Analytics have generated projections for Canada based on currently implemented policies. CAT has also created ranges for a 'fair share assessment' of what Canada's targets should be, to be in line with a global target of keeping emissions to 2 degrees and 1.5 degrees of warming from pre-industrial levels. The Climate Action Tracker's fair share assessment is based on data inputs from over 40 different effort sharing studies which cover a wide range of considerations of what is

considered to represent an equitable distribution[3] (Climate Action Tracker, 2017). Under this assessment, Canada's current INDC is rated as highly insufficient (Climate Action Tracker, 2017). In order to reach the 2-degree target under a fair share assessment the Climate Action Tracker estimates that Canada's INDC excluding LULUCF must be between 457 and 318 $MtCO_2e$ and between 318 and 121 $MtCO_2e$ for a 1.5 degree target by 2030. This is a substantial gap from Canada's current target of 523 $MtCO_2e$ which translates to 621 $MtCO_2e$ when excluding LULUCF (Climate Action Tracker, 2017).

Canada's Current Federal Policy

In 2016 Canada released the Pan-Canadian Framework as the first national plan to meet or exceed Canada's 2030 target (Flanagan et al, 2017). The plan laid out many measures including a mandatory price on carbon, accelerated phasing out of traditional coal by 2030, performance standards for natural gas electricity generation, the development of a Canada wide-strategy for zero emission vehicles by 2018, "net zero energy ready" model building codes by 2030 and increased industrial sector energy efficiency (Flanagan et al, 2017). Provinces will have the option of implementing either a carbon tax, or a cap and trade program by 2018 under the conditions that a) the carbon tax will start at a minimum of $10/tonne in 2018 and will rise to $50/tonne in 2022 and b) that a cap-and-trade program must have a 2030 emissions reduction target that is at a minimum equal to Canada's 30% reduction target with annual caps declining until at least 2022 that are at minimum in line with projected emissions reductions resulting from the carbon price in that year (Flanagan et al, 2017). With policies enacted as of November 1st, an independent policy analysis by the Climate Action Tracker states that Canada is likely to be between 674-757 $MtCO_2e$ excluding LULUCF (Climate Action Tracker, 2017). If the

Pan-Canadian Framework is fully implemented however, Climate Action Tracker estimates that Canada could reach GHG emissions excluding LULUCF of between 507-591 $MtCO_2e$ (Climate Action Tracker, 2017). In Canada's "Mid Century Long Term Low-Greenhouse Gas Development Strategy", a 2050 target of 80% reduction from 2005 level emissions including LULUCF was set (65% from 2005 levels excluding LULUCF) (Government of Canada, 2016). This target is based on the IPCCC Fifth Assessment Report which states that global GHG emission reductions between 75 to 95% below 2010 levels are needed to remain within a >50% chance of limiting global temperature rise to 1.5 degrees Celsius (Government of Canada, 2016).

Research Questions

The questions which guide this research are: How do the provincial allocations of Canada's 2030 INDC and a 2030 2-degree emissions target using a multi-criteria weighted sum model based on burden sharing principles differ from 2030 provincial goals? What impact does the province of Alberta have on the required reductions when meeting only their provincial goal?

By answering these questions, the research on the use of burden sharing rules to allocate Canadian provincial emissions targets will be furthered. While the allocation of carbon dioxide emissions is a widely researched subject, little work has been done on the use of burden sharing rules to allocate emissions targets among provinces. Furthermore, the author is unaware of any research that has been done on combining multiple burden sharing rules for the allocation of provincial emissions targets in Canada. The impact of Alberta's unambitious provincial emissions goal on the allocated reductions of other provinces under this allocation

model will help showcase the role of Alberta's provincial reductions in the wider scope of Canada's emission reductions.

Literature Review

Emissions Allocations Methods

Many different methods on how to allocate the burden of GHG emission reduction targets at the national, state and firm levels have been proposed in climate negotiations and literature. The difficulty of allocating emissions reductions requirements, and or emissions permits, is compounded by deciding on which principles the distribution will be based on. The two most prevalent categories of allocation principles found in the literature are fairness and efficiency (Zhou & Wang, 2016). The distinction between these two categories is that fairness focuses on concepts of distributive justice while efficiency focuses on the economic efficiency of emissions reductions (Zhou & Wang, 2016). Under these two general categories, there are many proposed methods for the distribution of CO_2 emissions permits and or reduction responsibilities. Zhou & Wang (2016) classified these methods into four different categories, namely the indicator approach, the optimization approach, the game theoretic approach and the hybrid approach. The optimization approach focuses on making the allocation as economically efficient as possible, i.e. allocating emission reduction requirements to where they are the most cost effective to do so. In this sense, the optimization approach regards economic efficiency as the highest priority. An example of this approach is a study by Gomes and Lins (2008) which used a zero-sum gain model to distribute emissions permits amongst Annex I and non-Annex I countries. The game-theoretic approach is based on the requirement

for negotiations between participants, where each player aims to win as many permits as possible to their benefit. The allocations in the game-theoretic approach are finalized when an equilibrium is reached. This process can be undertaken at the international, sub-national and firm levels and can be used to allocate initial permits in a cap and trade program (Zhou & Wang, 2016). The most commonly used allocation approach is the indicator method which refers to the distribution of emissions permits, or reduction targets, based on indicators which represent burden sharing rules and principles. The indicator approach can be broken up into two subcategories, single indicator and composite indicator. The distinction between the two is that single indicator relies on the use of just one indicator but may use multiple methods or rules based on that indicator for its emission allocation. In contrast, the composite indicator approach uses multiple indicators representing different criteria to create a composite index for the assignment of reduction targets or emissions permits (Zhou & Wang, 2016). Finally, the hybrid approach uses a mixture of different methods in its allocation and can incorporate multiple allocation approaches. While this method can integrate a range of criteria into its analysis, it can often have complex methodologies resulting in a lack of transparency of the results (Zhou & Wang, 2016). This paper is primarily concerned with the composite indicator approach due to its ability to incorporate various principles and criteria which better represent the heterogenous circumstances of Canadian provinces, while also being transparent and easy to understand in its results.

The Composite Indicator Approach

The main challenges associated with a composite indicator approach are found in the choosing of an appropriate Multi-Criteria Decision Analysis (MCDA) method, choosing criteria,

and assigning weights for the different indicators. A popular MCDA method is the weighted sum method which combines indicators in aggregate. One example of the use of the weighted sum method is a study by Ringius et. al (1998). This study used three different weighted sum formulae to distribute emissions reduction requirements between OECD countries based on the principles of ability to pay (GDP and GDP/capita), efficiency (emissions/GDP), responsibility (emissions/capita and historic emissions) and egalitarianism (population). The results from these allocations were compared against the principle of horizontal equity, defined by an equal reduction in welfare amongst the OECD countries (as a percent of national income loss). Another example is a study by Yi et al. (2011) which built on Ringius et al. (1998) and used a MCDA weighted sum model in the distribution of emission intensity targets between Chinese provinces based on the principles of ability to pay (GDP/capita), efficiency (emissions/unit of industrial added value) and polluter pays (historic emissions). In both studies the weightings were assigned using multiple cases to create a distribution where one criterion is weighed more heavily than the rest[4]. As with the single indicator approach, the choice of indicators is integral to the results of the allocation. While there have been many different allocation proposals for the national, state, and firm levels[5], there is no fully agreed upon definition of which principles and indicators best represent equity**.** An advantage that the composite indicator approach has is that through the incorporation of multiple principles and criteria, the results have the potential to be more acceptable to a range of stakeholders than a distribution which focuses solely on one.

Indicator	Allocation criterion	Allocation rule
Population	Egalitarianism	Equal adult per capita permits
		Equal per capita permits
		Equal future per capita permits with discounted historical responsibility
		Equal past and future per capita permits
		Equal per capita permits by C&C
		Equal per capita permits by CDC
Emission	Sovereignty/grandfathering	Proportional permits to historical emissions (country/firm)
	Polluter pays	Proportional reductions to a historical level
	Historical responsibility	Proportional reductions to cumulative emissions
Energy	Sovereignty/grandfathering	Proportional permits to energy consumption
		Proportional permits to energy production
GDP	Economic activity	Proportional permits to GDP
	Ability to pay	Proportional reductions to GDP
	Horizontal equity	Equal net abatement cost to GDP
Per capita GDP	Ability to pay	Proportional reduction to per capita GDP
	Vertical equity	Equal net abatement cost to per capita GDP
Emission intensity	Merit (efficiency)	Proportional reductions to emissions per unit of GDP
		Proportional reductions to emissions per unit of GDP by C&C
		Proportional permits to emissions per unit of production outputs (*also called benchmarking*)

Note: C&C = contraction & convergence; CDC = common but differentiated convergence.

Figure 1 Summary of Common Emission Allocation Principles Zhou & Wang 2016

Different Allocation Principles and Criteria

One of the most commonly cited works in the burden sharing literature is a 1990 paper by Adam Rose titled "Reducing Conflict in Global Warming Policy: The Potential of Equity as a Unifying Principle." Rose examines the implications of several international equity criteria such as horizontal equity, vertical equity, and sovereignty (Rose, 1990). Rose would later go on to present 10 different equity criteria for emissions distributions under the subcategories of allocation based and outcome based (Rose, 1998). Rose's initial paper was followed by the exploration of a wide range of burden sharing in studies such as Vaillancourt and Wauub (2004), Ringius et al. (1998, 2002), Rose and Stevens (1993), Berkand den Elzen (2001) and Rose and Zhang (2004). A summary of the most commonly used criteria and their operational rules are can be seen in Table 1. by Zhou & Wang (2016). A brief description of some of these allocation based principles can be seen in figure 1.

Grandfathering

The grandfathering criterion (commonly reffered to in the literature as 'sovereignty') refers to the distribution of emissions permits proportional to the status quo (Rose, 1992). This is based on the belief that emissions allocations should be based on the status quo. This rule implies that a status quo right is constituted by past usage and custom (Bohringer et al, 2006). In practice this means that the largest emitters will receive the largest share of emissions permits (Zhou & Wang, 2016). The indicators used for this principle can be cumulative historic emissions, cumulative historic per capita emissions or emissions per capita from a target year (Zhou & Wang, 2016). In contrast to this criterion is the historic responsibility criterion which refers to the distribution of emission reductions in proportion to cumulative historic emissions.

This criterion is often favoured by developing nations and would imply large scale reductions from OECD or Annex I countries (Zhou & Wang, 2016). A variation on the historic responsibility criterion is the polluter pays critereon which distributes emissions reductions proportional to a historical level.

Ability to Pay

The ability to pay principle refers to the distribution of emission reductions proportional to GDP or GDP/Capita. This principle is based on the belief that wealthier participants should bear more of the reduction burden than poorer ones (Zhou & Wang, 2016). Ability to pay is often linked to vertical equity which implies that participants with a higher capacity to pay should take on a greater economic burden (Rose, 1990). Other allocation principles based on GDP are horizontal equity and the economic activity criterion. Horizontal equity aims to equalize economic cost in change of GDP/capita while economic activity assigns emissions permits proportional to GDP with the goal of preserving economic integrity (Ringius et al., 1998).

Egalitarianism

The egalitarianism principle refers to the principle that everyone has an equal right to emit. This principle aims to equalize emissions per capita between the different parties (Zhou & Wang, 2016). There are multiple methods that have been proposed using population as an indicator including the contraction and convergence (C&C) approach (Boehringer et al., 2004). Noting the significant difference in national per capita emissions this approach proposes a gradual reduction and equalization of emissions from all nations to a sustainable level while recognizing the need for a substantial reduction in emissions (Boehringer et al., 2004). An

extension of this theory is the Common but Differentiated Convergence (CDC) approach. Like the principle of common but differentiated responsibility, the CDC approach differentiates between Annex I and Annex II countries by allowing for the emission per capita of Annex II countries to first rise to a level above the global average before eventually converging (Zhou & Wang, 2016). The egalitarian principle is fundamentally opposed to the principle of grandfathering where the former aims to distribute emissions permits based on equalizing per capita emissions, and the latter aims to distribute emissions permits relative to the status quo. Boehringer & Welsch (2006) attempted to use convergence to reconcile these principles by starting with initial allocations to represent grandfathering (referred to as sovereignty) and eventually shifting towards allocations representative of the egalitarian principle.

Efficiency (Merit)

The merit allocation principle seeks to reward carbon efficient parties and parties who have actively reduced the emissions intensity of their economies. This principle also represents the emission reduction capacity wherein an economy with high emissions/GDP has the room to increase efficiency (Zhou and Wang, 2016). The application of this principle can be done by distributing emissions reduction responsibilities proportional to the emissions per unit of GDP (Torvanger & Ringius, 2002). In practice this principle punishes carbon inefficient entities and rewards carbon efficient ones creating an incentive to increase efficiency (Zhou & Wang, 2016). When efficiency is used as an outcome based principle – meaning that the allocation is not in the form of emission reductions but rather in required efficiency – it may not in fact imply cumulative emission reductions as total emissions are not constrained. When efficiency is used

as an allocation-based principle, however, the result will imply cumulative emission reductions. This principle can be linked to an economic efficiency principle based on the idea that each unit of carbon removed becomes more expensive than the last (Boehringer, 2014)

Related Studies

There has been little literature on emissions allocations among Canadian provinces and the author is unaware of any which has attempted to incorporate multiple burden sharing principles into the allocation of provincial emission reductions. An important contribution to this subject was on the impact of allocating provincial emissions reduction targets based on the use of singular burden sharing principles by Boehringer et al. (2014). The single indicator method was used to compare the distributions based on the allocation-based principles of equal CO_2/capita (egalitarian), proportional to historic emissions (grandfathering) and GDP/capita (ability to pay)[6]. Boothe & Boudreault (2016a) found that there existed an emission gap between the cumulative emissions goals of Canadian provincial plans and the federal 2020 and 2030 targets. In their follow up paper, Boothe & Boudreault built on the work by Boehringer (2014) and compared the implications of the burden sharing rules grandfathering, egalitarianism and economic efficiency in closing the 2020 emission gap[7]. It was found that the grandfathering and economic efficiency burden sharing rules had similar distributions and were closely related to the four largest emitting province's emissions goals[8]. The egalitarianism burden sharing rule presented significantly different allocations and implied heavy reduction burdens on Alberta and Saskatchewan with comparatively light burdens on Ontario and Quebec. Boehringer et al. (2014) concluded that while individually the rules do not help explain the division of effort between provinces, a combination of the philosophically based burden

sharing principles could form the basis for a 'fair' sharing of the emission reductions while being more likely to be accepted by the provinces.

Guiding Principles from the Literature

Through the studying of the literature, the methodology for this paper has been constructed. Out of the different emission allocation approaches, the indicator approach was chosen out of the main four categories of methods defined by Zhou & Wang (2016). To incorporate multiple burden sharing rules, the weighted sum MCDA method employed by Ringius et al. (1998) was used. More specifically, formula 1 from Ringius et al. (1998) was used due to its ability to allocate percent reduction targets based on the indicators relation to the national average. Following work done by Boehringer et al. (2014) the allocation principles of 'grandfathering' and 'ability to pay' were chosen along with the efficiency principle which drew its inspiration from Yi et al. (2011) and Ringius et al. (1998). In both Boehringer et al. (2014) and Boothe & Boudreault (2016b) grandfathering and egalitarian principles are shown to have allocations which are drastically different from each other. The egalitarian principle was shown to have allocations which implied drastic differences from provincial projections by implying prohibitively large reductions in provinces with high emissions per capita, such as Alberta and Saskatchewan, and allocations which allow for significant emissions growth in provinces with low emissions per capita including Ontario and Quebec. Although egalitarianism has solid footing as a philosophical principle, the grandfathering principle is more relevant in Canadian policy, such as the Vancouver Declaration, while implying less extreme allocations. By opting for the inclusion of the grandfathering principle without the egalitarian principle, there will be less variability in provincial allocations between weighting scenarios. In line with Yi et al. (2011) and

Ringius et al. (1998) a sensitivity analysis is conducted by alternating weighting scenarios which place the most weight on a specific indicator and analyzing the impact it has on provincial allocations.

Methodology

Overview

The objective of this study was to examine the application of a Multi-Criteria Decision Analysis tool using a weighted-sum composite indicator approach in distributing the allocation of emission reduction responsibilities among Canadian provinces. The cumulative distribution targets are based on Canada's 2030 INDC as well as targets from the Climate Action Trackers independent "Fair Share" targets that Canada should reach in order to be in line with a 2-degree scenario[9]. The purpose of this study was to combine multiple burden sharing rules for the allocation of 2030 emissions targets and to compare provincial emissions goals to these allocations. Provincial goals were taken from provincial climate change plans and, where a emission reduction goal had not been identified, estimates by Boothe & Boudreault (2016b) were used. These goals can be viewed in appendix I. Furthermore, the effect of Alberta committing only to its provincial emissions goal on meeting Canada's 2030 INDC and 2-degree fair share target under this allocation model are explored. A sensitivity analysis of different weighting scenarios generated a range of provincial emission allocations for 2030 to show the implication that the weighting of each criteria had on the emissions allocation. The different weighting scenario allocations[10] were compared to provincial 2030 emissions goals to highlight the level of ambition required to meet these allocations. Canadian Territories were excluded

from the allocations due to the unique circumstances resulting in indicators being less representative of their principles. Emissions for the Territories are assumed to remain constant.

Burden Sharing Rules and Criteria

The burden sharing rules that will be used in this study are based on the principles of grandfathering, ability to pay and efficiency. The respective criteria to represent these principles are CO2/capita, GDP/Capita and CO_2/GDP using data from Statistics Canada for the year 2015[11]. Unlike the egalitarian principle, grandfathering allocates more emissions permits to provinces that have a higher CO_2/capita. To account for this, the inverse of the CO_2/capita indicator value was taken for each province. The implication for these indicators are that higher GDP/capita and CO_2/GDP will allocate a higher reduction burden while a higher CO_2/capita will allocate a lower reduction burden. 2015 has been chosen as the target year for this data collection as it is the most recent year of available provincial emissions data. The required data for the indicators has been taken from Canada's national greenhouse gas inventory reports and Statistics Canada reports while data for the national emission allocation targets was taken from Canada's 2030 INDC as well as data shared with the author by Climate Action Tracker from their "fair share" analysis of Canada.

Formulae

$$Y_i=\{w_A A_i/A+w_B B_i/B+w_C C_i/C\ \}Z$$

Where Y_i is the percent emission reduction for province i. A_i is the CO_2/GDP for province i, B_i is the GDP/capita for province i, and C_i is the inverse of the CO_2/capita for province i. A, B, C represent the national average of their respective indicators. The weights for each indicator are

represented by w where $w_A+w_B+w_C = 100$. Z is a scaling factor and is applied to each province's allocation to make the total emissions abatement equal to the specified national target.

Scaling Factor

To calculate the scaling factor, the required national reduction burden implied from the difference between the total of the 2015 provincial emissions and the national emissions target is divided by the sum of the provincial emissions for the reference year subtracted by the sum of the provincial reduction allocations pre-scaling. This can be represented by the formula:

$$Z_i = R_i / (e_t - \Sigma A_n)$$

Where Z represents the scaling for national emissions reduction target i, where R represents the required reduction burden from the reference year national emissions (2015) to meet the national emissions reduction target i, where e_t represents the total provincial emissions for the reference year and where ΣA_n represents the sum of the allocated emissions levels pre scale ($\Sigma A_n = \Sigma(w_A A_i/A + w_B B_i/B + w_C C_i/C)$). The scaled percent reductions are then converted into their implied emission levels in $MtCO_2e$ for each province. These emission allocations are then converted to give the implied emission reductions in terms of 2005 level emissions. The absolute change from the provincial goals is taken to analyse the deviation from provincial goals under each weighting scenario's allocation. In the allocations which use Alberta's 2030 provincial goal in place of an allocated target, Alberta's emission levels pre-scale are considered at 274.1 $MtCO_2e$ for the calculation of the scaling factor.

National Required Reduction Burdens

The national required reduction burdens used in in the calculation of the Z scaling factor are calculated by taking the difference between the cumulative provincial 2015 emissions in

$MtCO_2e$ excluding LULUCF and the national emissions target (i.e. Canada's 2030 INDC of 523 $MtCO_2e$ excluding LULUCF). This assumes that emissions of the Territories will remain the same between 2015 and 2030. To calculate the national emissions reduction burdens for the scenarios which do not calculate an allocation for Alberta, it is assumed that Alberta will meet their 2030 provincial goal of 270 $MtCO_2e$ by 2030. To account for this modest reduction from 2015 levels, the equivalent 4.1 $MtCO_2e$ provincial reduction is subtracted from the national required reduction burden for the relevant allocations.

Results

Using the model described in the methodology, emission reduction targets were allocated across the provinces based under four different weighting scenarios. The operational rule for this formula is that a theoretical province which has indicator values equal to the national average will have a reduction responsibility equivalent to that of Canada's national percent emission reduction requirement. This implies that a province that is above average on the indicators will be assigned a reduction burden greater than Canada's national percent emission reduction requirement, while a province which is below the average will be assigned a lesser burden. The different weightings represent scenarios where: each indicator is valued equally, where grandfathering (CO_2/Capita) is valued most highly, where efficiency (CO_2/GDP) is valued most highly, and where ability to pay (GDP/Capita)[12] is valued most highly. Following the work of Boothe & Boudreault (2016a, 2016b) and Boehringer (2014), Canada's national targets have been incorporated without accounting for LULUCF. This is because Canada's National Inventory Report (NIR) to the UNFCCC does not include LULUCF. Furthermore,

Canada's 2030 INDC had to be considered excluding LULUCF in order to remain consistent with the CAT's fair share assessment.[13] Provincial goals are included in figures 2-5 to show the level of ambition needed for each province to update their goals to meet the allocation results.[14] A full list of results can be found in Appendix III-VI.

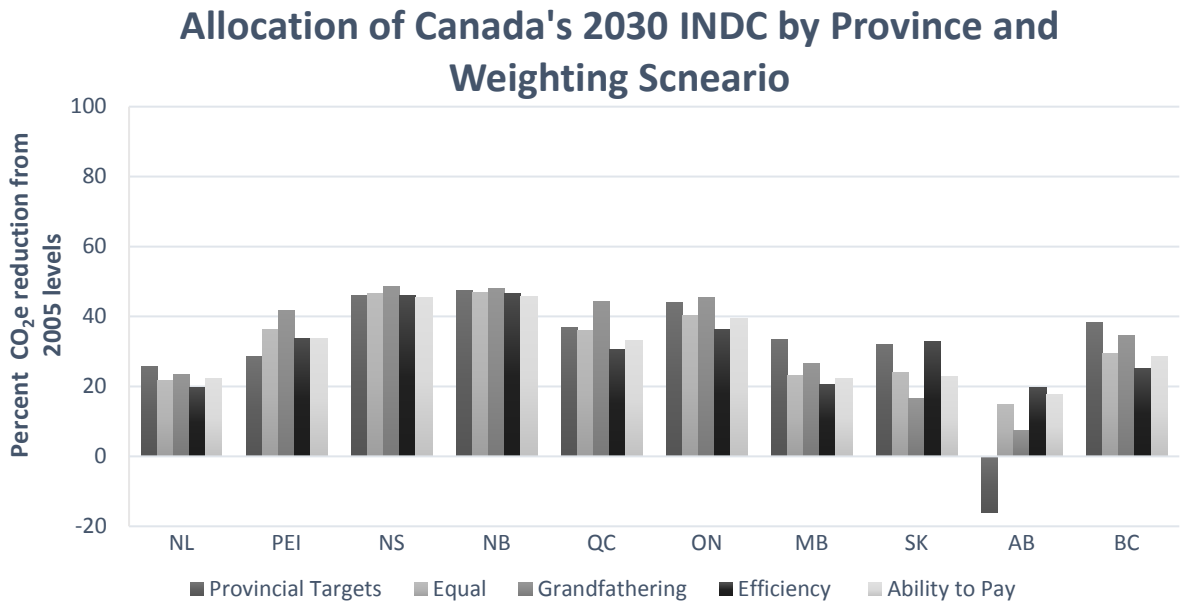

Figure 2 Allocation Results for Canada's 2030 INDC

Allocating Canada's 2030 INDC results in Ontario reducing emissions from 2005 by between 36-45%, Quebec reducing by between 31-44%, British Columbia by between 25-35% and Manitoba by between 21-27%. For each of these provinces the efficiency weighted scenario allocated the least stringent reduction while the grandfathering scenario allocated the most stringent. Alberta reduces emissions by the least at between 8% in the grandfathering weighted scenario to 20% in the efficiency weighted scenario while Saskatchewan reduces by a range of 17% in the grandfathering weighted scenario to 33% in the efficiency scenario. Of the Atlantic provinces, Nova Scotia and New Brunswick have almost identical allocations with Nova Scotia between a 45-49% reduction and New Brunswick between 46-48%, Prince Edward Island

reduces by between 34 and 42% and Newfoundland and Labrador, with the least stringent reduction of the Atlantic provinces, reduces by between 20-23%. Nova Scotia, New Brunswick and Prince Edward Island experience the least stringent reductions under the ability to pay weighted scenario with the most stringent under the grandfathering weighted scenario while Newfoundland and Labrador reduces by the least under the efficiency weighted scenario and the most under the grandfathering weighted scenario.

Newfoundland and Labrador, Manitoba, Alberta and British Columbia's provincial goals are most closely in line with the grandfathering weighted allocation (CO_2eq/capita) While Nova Scotia, PEI, and Saskatchewan's provincial goals are most closely in line with the efficiency weighted allocation (CO_2eq/GDP). Finally, Quebec, Ontario and New Brunswick's provincial goals are closest to the equal weighted scenario. Overall the equal weighted scenario was the closet to the provincial goals with the average absolute change from provincial goals at 9.4%[15]. In the allocation of the 2030 INDC some provinces are given allocations which are less ambitious than their provincial goals. Manitoba, Saskatchewan and British Columbia experience allocations which are significantly above their provincial goals. The low stringency of the allocations is a result of the increase in ambition allocated to Alberta compared to their provincial goal. Alberta is Canada's largest emitting province and made up 38% of Canada's total emissions in 2015 excluding LULUCF. Despite having the least stringent reduction allocation results, Alberta requires the highest level of ambition to meet the allocation target with a gap of 20-31% between the provincial goal and the allocated targets.

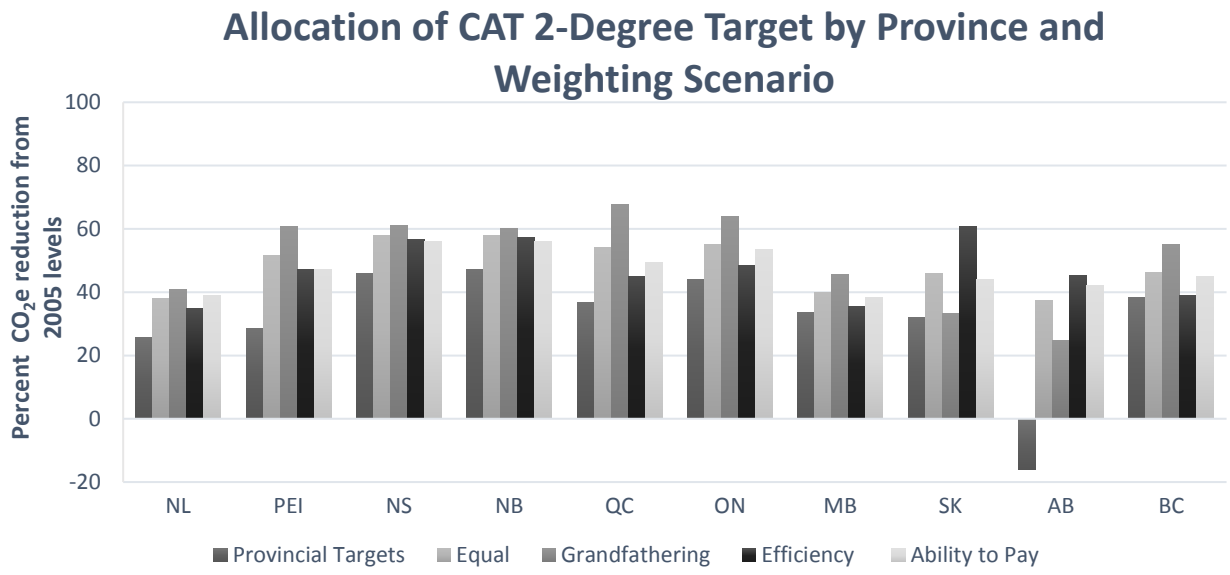

Figure 3 Allocation Results for CAT 2-Degree Target

In order to be in line with a 2-degree scenario an emission target for Canada has been set at 378 $MtCO_2eq$ for the year 2030. This target is based on the Climate Action Tracker's 2-degree fair share range[16]. This national target is equivalent to a 49% reduction from 2005 levels excluding LULUCF. Shown in figure 3, to reach this Ontario reduces by between 48-64%, Quebec reduces by between 45-68%, British Columbia reduces by between 39-55%, Manitoba reduces by between 35%-46%, Saskatchewan reduces by a wide range of between 33-61% and Alberta reduces by between 25-45%. As in figure 2, Alberta and Saskatchewan experience the least stringent allocations under the grandfathering weighted scenario and the highest under the efficiency weighted scenario while Ontario, Quebec, British Columbia and Manitoba experience the opposite. In the Atlantic, Nova Scotia and New Brunswick have near identical allocations and reduce emissions by between 56-61% while Prince Edward Island reduces by between 47-61% and Newfoundland and Labrador reduces by between 35-41%. Once again, the least stringent allocation for Nova Scotia, New Brunswick and PEI is the ability to pay weighted

scenario and the highest is the grandfathering weighted scenario while Newfoundland and Labrador's least stringent reduction is in the efficiency weighted scenario and the highest is the grandfathering weighted scenario. With the higher national reduction burden, the required reductions among the other provinces are substantially increased and the range in allocation results between the different weighting scenarios increased.

Predictably the weighting scenario most in line with Alberta and Saskatchewan's provincial goals is the grandfathering weighted scenario. Newfoundland and Labrador, Prince Edward Island, Quebec, Ontario, Manitoba and British Columbia's goals are closest to the efficiency weighted scenario, while Nova Scotia and New Brunswick's goals are closest to the ability to pay weighted scenario. Under the CAT 2-degree fair share reduction target, no provinces are allotted targets less stringent than that of their provincial goals. Overall, the efficiency weighted scenario was the closest to the provincial goals with an average increase in reduction by 16% from provincial goals required to meet the CAT 2-degree allocation.

The 2030 provincial goals, assuming they are met, add up to a 2030 emission level of 573 $MtCO_2eq$. To meet Canada's 2030 INDC excluding LULUCF, provinces will need to cumulatively reduce by a further 50 $MtCO_2eq$ from their goals. To reach the CAT 2-degree scenario target a further reduction of 186 $MtCO_2eq$ from provincial goals is required. For the allocations of both targets, Alberta is on average required to make the most substantial change from their goal. Alberta's provincial GHG emission goal allows for a 16% growth in emissions from 2005 levels by 2030 and is the only province which plans to grow its emissions. Alberta's goal is far from the 8-20% reduction in the 2030 INDC allocation and the 25-45% reduction in the CAT 2-degree allocation. To demonstrate the importance of Alberta's emissions in the

context of a national reduction, Canada's 2030 INDC and the CAT 2-degree targets are reallocated using Alberta's proposed 2030 goal of 270 $MtCO_2eq$.

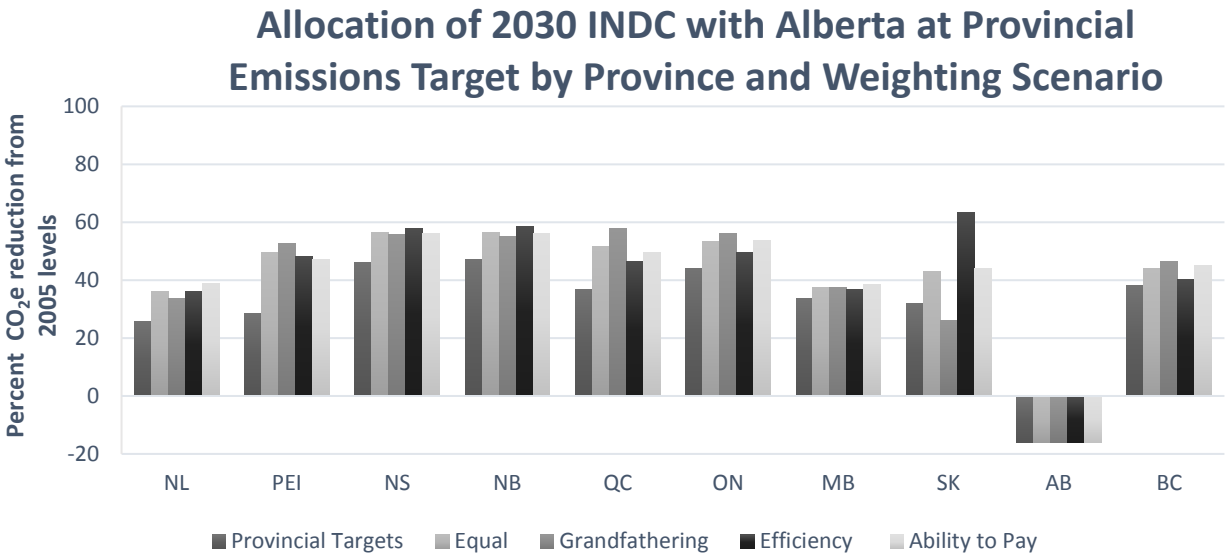

Figure 4 Allocation Results for Canada's 2030 INDC with Alberta reducing emissions to its provincial Goal

As shown in figure 4 without substantial reductions from Alberta, the reduction burden falls more heavily on the remaining provinces with all provinces experiencing increased reduction burdens. Saskatchewan simultaneously experiences the most stringent and the most lenient of the allocations and 26-63% cut in emissions under the grandfathering and efficiency weighted scenarios respectively. Nova Scotia reduces by 56-58% while New Brunswick reduces by 55-59%. For both provinces the least stringent scenario is the grandfathering weighted scenario and the most stringent is the efficiency scenario. Quebec, Ontario and British Columbia reduce by between 46-58%, 50-56%, and 40-46% respectively. Each of these provinces are allocated the least stringent targets under the efficiency weighted scenario and the most under the grandfathering weighted scenario. PEI reduces emissions by between 47% under the efficiency weighted scenario to 53% under the grandfathering scenario. Finally, Manitoba is allocated a reduction with a small range of between 37% under the efficiency weighted

scenario to 38% under the ability to pay weighed scenario. To meet this allocation provinces, will on average across all weighing scenario's, need to increase the ambition of their provincial goals by 17% in order to reach Canada's national 2030 INDC with Alberta committing only to its provincial goal.

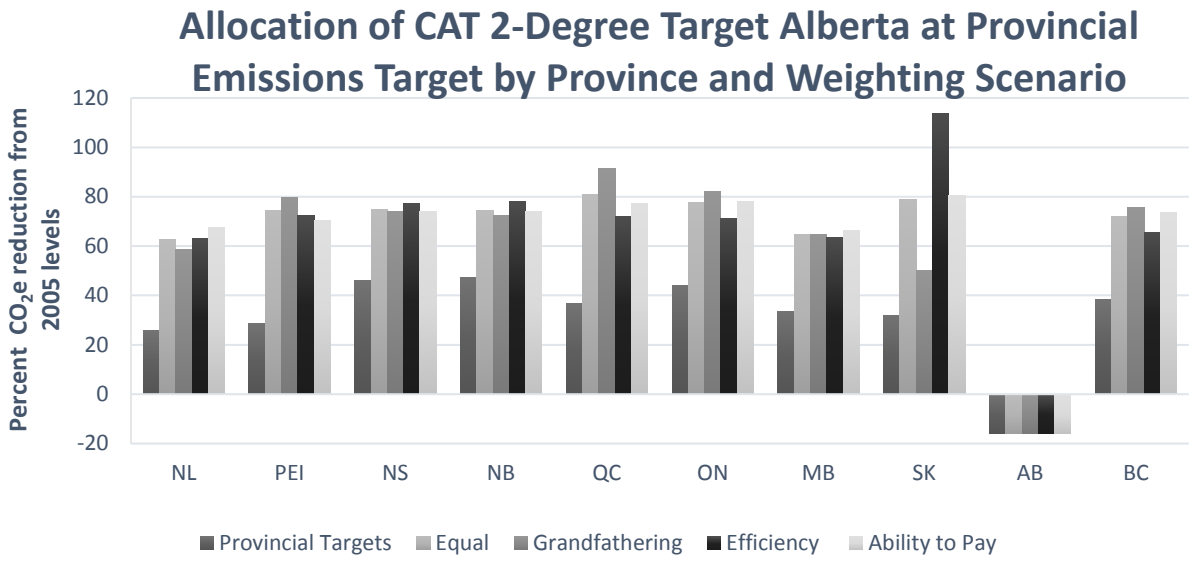

Figure 5 Allocation Results for CAT 2-degree target with Alberta reducing emissions to its provincial Goal

Under the CAT 2-degree allocation shown in Figure 5, the allocation of emissions reduction targets with Alberta committing only to its provincial goal implies heavy reduction burdens for the rest of the provinces. In the case of the Efficiency weighted scenario Saskatchewan must go as far as to have negative emissions at a 114% reduction. Nova Scotia, New Brunswick, Prince Edward Island and Ontario reduce by between 70-82% from 2005 levels. British Columbia reduces by between 66-76%, Newfoundland and Labrador reduces by between 59-68% and Quebec reduces by between 72-92%. As in the 2030 INDC allocation without Alberta, the weighting scenarios follow the same allocation pattern. Under the CAT 2-

degree allocation with Alberta committing only to its provincial goal, the remaining provinces are in most cases required to increase the strength of their goals by more than 50%.

Discussion

2030 INDC Allocation

The four different weighting scenarios used in this model imply substantial differences in their allocations. When involving all provinces, the grandfathering weighted scenario (CO2/Capita) favors Alberta and Saskatchewan with low reduction burdens, and as a result allocates higher reduction burdens to the remaining provinces than in any of the other scenarios. The efficiency weighted scenario (CO_2e/GDP) has the opposite implication and most heavily allocates reduction burdens to Alberta and Saskatchewan while allocating light burdens to the rest of the provinces. Notably, three of the top five emitters, Quebec, Ontario and British Columbia are allocated targets which are less stringent than their provincial goals. The ability to pay weighted scenario (CO_2e/GDP) has similar allocations to the efficiency scenario. The most significant differences between the ability to pay weighted scenario and the efficiency weighted scenario are for British Columbia which reduces by 3% more and Saskatchewan which reduces by 10% less under the ability to pay weighting scenario. The equally weighted scenario allocations are, as a function, always confined within the upper and lower limits of the weighted scenario allocations. On average, for the 2030 INDC allocation, the equally weighted scenario results in the lowest absolute change from the provincial goals. The incorporation of the CO_2/Capita indicator to represent grandfathering allows for fossil fuel intensive provinces such as Alberta and Saskatchewan to be buffered against the higher reductions implied under the CO_2/GDP and GDP/Capita indicators for the efficiency and ability to pay burden sharing

rules. Under the 2030 INDC allocation scenario, some provinces are given lighter allocation targets than their provincial goals. As stated earlier, this is in part due to the increased emission reduction allocation given to Alberta which accounts for a substantial proportion of the national required reduction. Although Alberta's percent reduction allocations are the lowest in every scenario, they simultaneously represent the largest departure from any province's 2030 reduction goals. When Alberta was simulated to keep their proposed 2030 goal of 270.1 $MtCO_2$ the allocations required almost every province to substantially increase the stringency of their goals[17]. On average across all weighting scenarios, to compensate for Alberta's BAU scenario, each province needed to reduce emissions by a further 14%. Creating a scenario which is in line with the Climate Action Tracker's 2-degree fair share estimate, with Alberta's emissions levels remaining at their goal, becomes even more difficult.

CAT 2-Degree Fair Share Target Allocation

To reach the 2-degree scenario, provinces will need to make heavy emissions reductions targets that may imply a substantial loss in welfare for some provinces. In the 2-degree target allocation, a national reduction of 47% from the 2005 levels is required. This translates to a required increase in reduction by 32% from the cumulative provincial goals. Under the 2-degree allocation, each province on average across all weighting scenarios was required to reduce emissions by a further 21% from their goals. With Alberta committing only to their provincial goal however, a much heavier burden is allocated to the remaining provinces. On average across all weighting scenarios, a reduction by 67% from 2005 levels by 2030 is needed of the remaining provinces to meet the 2-degree national target without Alberta reducing beyond its provincial goal. This translates to an average increase in ambition by 54% from provincial goals.

Under the efficiency weighting scenario without Alberta, Saskatchewan will need to reduce emissions by 114%. This is only possible using carbon credits, LULUCF offsets, or carbon capture and storage technology which is still in its infancy.

Strengths

As Boothe & Boudreault (2016)[b] and Boehringer et al (2014) found, the application of single burden sharing rules in Canada can imply vastly different reduction burdens depending on the selected rule. Canadian provinces are heterogenous in their distribution of wealth, population, emissions, and economies, which makes relying on any one burden sharing rule to be heavily in the favor of certain provinces. The attempt to combine multiple burden sharing rules in this paper aims to incorporate different burden sharing preferences to avoid overly favoring certain provinces. From the allocations given by this model, there have been several desirable qualities. The first is that the allocated reductions for the 2030 INDC for every weighting scenario have been on average significantly closer to the provincial goals than what would be implied by an equivalent 30% reduction. Perhaps the most desirable quality however is that the 2030 INDC allocations reduce the difference in ambition required for each province to update provincial goals to meet the allocations. This is represented by a lower standard deviation of the absolute change from provincial goals than what is found under an equal 30% reduction. By allocating a reduction burden to Alberta that is less ambitious than what would be implied if Alberta chose to adopt a cap-and-trade program under the Pan-Canadian Framework (minimum 30% reduction from 2005 levels by 2030), there is a better chance of incorporating Canada's largest emitting province into a nationwide cap and trade program while still meeting Canada's 2030 INDC.

Potential Application of Results as a Cap and Trade Program

Under the Pan-Canadian Framework on Clean Growth and Climate Change, provinces who choose to use employ a cap and trade program, as opposed to a carbon tax, must meet the minimum requirement of Canada's national target of a 30% reduction from 2005 levels by 2030 (Flanagan et al., 2017). By requiring a minimum 2030 reduction target of 30% for provinces who choose to use a cap-and-trade program, Canada has in effect applied a grandfathering burden sharing rule[18]. Given that Canada's current federal cap and trade policy resembles the burden sharing principle of grandfathering, it is likely that a distribution which most heavily favors allocating emissions in proportion to historic amounts would be the most favourable from a federal point of view. A model such as this one could be used for the initial allocations in a nation-wide cap and trade program or to allocate emission reduction targets. A cap and trade program would allow for more flexibility as provinces are able to purchase or sell carbon credits to meet their preferred emission levels. In practice this would result in Alberta likely buying permits from provinces with a surplus allocation such as British Columbia, Manitoba and Saskatchewan. Recently, Ontario and Quebec have formally linked up with California to fully integrate their carbon markets. While Nova Scotia has also elected to choose a cap and trade program, their program is currently isolated from any other carbon markets and emissions permits are strictly internal. Provincial plans for PEI, Newfoundland and Labrador and New Brunswick have yet to be stated and have up to spring of 2018 to identify their plans before the federal backstop minimum carbon price comes into effect (Flanagan et al., 2017). Due to the 30% minimum reduction requirement by 2030 there is little hope for a Canada wide cap-and-trade program under the current requirements. Without differentiated reductions

requirements it seems highly improbable that Canada will be able to incorporate Alberta with a mandatory increase in emissions reductions by 40% from their provincial goal.

Provincial Business as Usual Projections

While this paper has largely focused on comparing the allocations of the multi-criteria weighted sum model to provincial goals, the provincial progress towards these goals must be recognized. As of 2017, Environment and Climate Change Canada's provincial emissions projections indicate that only Nova Scotia is on track to meet the provincial goal (Auditors General, 2018). Saskatchewan and Manitoba are the furthest from their goals with a reduction by 33% and 36% from their business as usual projection required to meet the 2030 provincial goals. While these projections do not account for potential international emissions reductions resulting from Quebec and Ontario's cap and trade program with California, it is a bad sign that provinces currently require on average a 19% reduction below their business as usual emissions projections to meet the goals which cumulatively fall short of Canada's 2030 INDC. This fact however does not render the allocations under the multi-criteria weighted sum model irrelevant. When applying the grandfathering weighted scenario allocation for Canada's 2030 INDC the allocation still had several desirable qualities. Although the average required reduction from provincial business as usual projections to meet the allocations was higher than the required reductions from provincial goals to meet the allocations, these reductions are on average still less than would be implied under an equivalent 30% reduction. Whereas an equivalent 30% target would imply reduction burdens prohibitively ambitious for Canada's largest emitting province Alberta, the grandfathering weighting scenario allocates a reduction target of 7% which is much more attainable for Alberta than a 30% reduction target.

Limitations

Limitations to this study are mainly linked to its methodology. A goal of this paper was to provide a conceptual view on how the application of a model which incorporated multiple burden sharing principles would allocate emission reductions targets for Canadian provinces. To showcase the possibilities of such an application, multiple weighting scenarios were used which significantly differ in their allocations. Because of this, no one allocation target can be given for a province and instead multiple weighting scenario allocations are used. Secondly, the indicators which are used may not represent the principles which they are attached to well as other indicators. For instance, in this paper real GDP per capita was used to represent economic well-being for the ability to pay principle, however, this principle may be better represented using a GDP measurement which considers the cost of living in that province. The principles used in this paper were selected by the author after reviewing the relevant literature. There are, however, many different allocation based burden sharing principles and some other combination of them may better represent a "fair" distribution of emissions reduction burdens in Canada.

Conclusion

For its 2030 INDC submission to the UNFCCC under the Paris Agreement, the Canadian government has selected a target of a 30% reduction from 2005 level emissions. The primary goal of the Paris Agreement has been to limit global temperature increase to 2 degrees above pre-industrial levels. Historically in Canada, it has been the provinces which have shown climate leadership through the development of targets and emission mitigation policies. With policies implemented as of November 1st, 2016, Canada is on track to reach 742 $MtCO_2e$ by 2030, 42%

above the 2030 INDC and 91% above an estimated 2030 2-Degree fair share target. On December 9th 2016, the Pan-Canadian Framework on Clean Growth and Climate Change was finalized. This framework formed a national strategy which incorporated each province in the hope of getting Canada on track to meet its 2030 commitment. Within this framework are the minimum requirements for provinces which choose a cap-and-trade program. These cap-and-trade requirements are closely linked to the grandfathering burden sharing principle by requiring a minimum emissions reduction cap of 30% by 2030. This paper has attempted to incorporate multiple burden sharing rules which differentiate emission reduction allocation targets to represent the differences in welfare, status quo emissions, and economic emissions intensity between Canada's provinces.

Using the multi-criteria weighted sum model to incorporate the principles of grandfathering, ability to pay and efficiency, reduction allocations were assigned to each province to meet Canada's 2030 INDC and a 2-degree fair share target. It was shown that the weighting scenario which is chosen will have significant implications on the provincial allocations with the grandfathering weighted allocation likely being the most favourable in the political climate as well as being the most likely to successfully incorporate Alberta into a nation-wide cap and trade program. When compared to the Pan Canadian Framework's participatory cap and trade program requirement of a 30% reduction from 2005 levels, every weighting scenario allocates reductions which, on average, result in less change from the provincial goals. Through the results from allocations with Alberta remaining at provincial levels, it has been clear that increasing the stringency of Alberta's provincial goal is important for Canada to reach its 2030 goal and integral to the possibility of meeting a 2-degree fair share

scenario. While some Canadian provinces under the 2030 INDC allocation have goals which are more stringent than what is allocated by the model, no provincial goals are in line with the 2-Degree fair share target let alone a scenario where Alberta meets only their provincial goal. An allocation such as this can be used to help guide and evaluate future climate change policy such as provincial emissions caps or provincial emissions targets. An allocation which is transparent in its methodology and is based on burden sharing principles may be able to create consensus between provinces on what is considered a fair distribution of Canada's emission burdens. Research on the incorporation of multiple burden sharing principles in the distribution of Canada's emissions reduction burdens can be furthered by exploring methods which may determine which principles are the most important amongst Canadian Provinces.

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Bibliography

Auditors General . (2018, March). *Office of the Auditor General of Canada*. Retrieved from Perspectives on Climate Change Action in Canada—A Collaborative Report from Auditors General: http://www.oag-bvg.gc.ca/internet/English/parl_otp_201803_e_42883.html#

Berk, M., & Den Elzen, M. (2001). Options for Differentiation of Future Commintments in Climate Policy: How to Realise Timely Participation to Meet Stringent Climate Goals? . *Climate Policy* , 465-480.

Böhringer, C., & Welsch, H. (2004). Contraction and Convergence of Carbon Emissions: the Implications of Permit Trading. *Journal of Policy Modeling*, 21-39.

Böhringer, C., Rivers, N., Rutherford, T. F., & Wigle, R. (2014). Sharing the Burden for Climate CHange Mitigation in the Canadian Federation. *Transitional Studies*.

Boothe, P., & Boudreault, F. (2016a). *By The Numbers: Canadian GHG Emissions.* London : Lawrence National Centre for Policy and Management.

Boothe, P., & Boudreault, F. (2016b). *By The Numbers: Sharing the Burden.* London : Lawrence National Centre for Policy and Management.

Climate Action Tracker. (2017). *Climate Action Tracker* . Retrieved from Canada : http://climateactiontracker.org/countries/canada.html

Climate Action Tracker. (2017, December). CAT Canada Numbers (Excel Document).

Environment and Climate Change Canada. (2017). *Environment and CLimate Change Canada .* Retrieved from Progress Towards Canada's Greenhouse Gas Emissions Reduction Target: https://www.ec.gc.ca/indicateurs-indicators/default.asp?lang=en&n=CCED3397-1&pedisable=true

European Commission. (1996). *European Commission Press Release Database.* Retrieved from Community Strategy on Climate Change - Council Conclusions : http://europa.eu/rapid/press-release_PRES-96-188_en.htm?locale=en

Flanagan, E., Plumptre, B., Duncan, K., & Tam Wu, K. (2017). *State of the Framework: Tracking Implementation of the Pan-Canadian Framework on Clean Growth and Climate Change.* Pembina Institute.

Gomes, E., & Lins, M. (2006). Modelling undesirable outputs with zero sum gains data envelopment analysis models. *Journal of the Operational Research Society* , 616-623.

Government of Canada . (2017). *Canada's 2017 Nationally Determined Contribtuion Submission to the United Nations Framework .* United Nations.

Government of Canada. (1992). *The Rio Earth Summit: Summary of the United Nations Conference on Environment and Development.* Government of Canada.

Government of Canada. (2016). *Canada's Mid-Century long Term Low-Greenhouse Gas Development Strategy.* United Nations.

Government of Canada. (2017). *Government of Canada.* Retrieved from Greenhouse Gas Emissions by Province and Territory : https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/greenhouse-gas-emissions/province-territory.html

Government of Canada. (2017). *Canada's 2017 Nationally Determinded Contribution Submission to the United Nations Framework Covention on Climate Change.* UNFCCC.

Grassi, G., House, J., Dentener, F., Den Elzen, M., & Penman, J. (2017). The Key Role of Forests in Meeting Climate Targets Requires Science for Credible Mitigation . *Nature and Climate Change*, 220-226.

Jaeger, C., & Jaeger, J. (2010). Three Views of Two Degrees. *Climate Change Economics* , 145-166.

Jan van Oldenborgh, G., van der Wiel, K., Sebastian, A., Singh, R., Arrighi, J., Otto, F., . . . Cullen, H. (2017). Attribution of Extreme Rainfall From Hurrican Harvey, August 2017. *Environmental Research Letters*.

Lang, C., Leuenberger, M., Schwander, J., & Johensen, S. (1999). 16 C Rapid Temperature Variation in Central Greenland 70,000 Years Ago . *Science*, 934-937.

Nelson, G. (2017, December 14). *SGD Knowledge Hub*. Retrieved from Doha Amendment Reaches 95 Ratifications: http://sdg.iisd.org/news/doha-amendment-reaches-95-ratifications/

Ringiusa, L., Torvangeram, A., & Holtsmarka, B. (1998). Can Multi-Criteria Rules Fairly Distribute Climate Burdens?: OECD Results from Three Burden Sharing Rules. *Energy Policy* , 777-793.

Rose, A. (1990). Reducing Conflict in Global Warming Policy: The Potential of Equity as a Unifying Principle. *Energy*, 927-935.

Rose, A., Stevens, B., & Edmonds, J. (1998). International Equity and Differentiation in Global Warming Policy. *Environmental and Resource Economics*, 25-51.

Statistics Canada. (2017). *Statistics Canada.* Retrieved from Real gross domestic product, expenditure-based, by province and territory: http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/econ50-eng.htm

Statistics Canada. (2017). *Statistics Canada.* Retrieved from Population by year, by province and territory : http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/demo02a-eng.htm

Torvanger, A., & Edmonds, J. (2002). Criteria for Evaluation of Burden-sharing Rules in International Climate Policy. *International Environmental Agreements*, 221-235.

UNFCCC. (2014). *United Nations Climate Change*. Retrieved from Copenhagen Climate Change Conference - December 2009 : http://unfccc.int/meetings/copenhagen_dec_2009/meeting/6295.php

United Nations. (1992). *United Nations Framework Convention on Climate Change 1992 Report.* United Nations.

United Nations. (2018). *United Nations Climate Change*. Retrieved from Kyoto Protocol : http://unfccc.int/kyoto_protocol/items/2830.php

United Nations Environment Programme. (2017). *The Emissions Gap Report .* Nairobi : United Nations.

Vaillancourt, K., & Waaub, J. (2004). Equity in International Greenhouse Gases Abatement Scenarios: A Multicriteria Approach. *European Journal of Operational Research* , 489-505.

Yi, W. J., Zou, L., Jie, G., Wang, K., & Wei, Y. (2011). How can China reach its CO2 intensity reduction targets by 2020? A regional allocation based on equity and development. *Energy Policy* , 2407-2415.

Zhou, P., & Wang, M. (2016). Carbon Dioxide Emissions Allocation: A Review . *Ecological Economics* , 47-59.

Appendix

I) Provincial 2030 Emissions Goals in $MtCO_2e$

Province	Percent Emission Reduction Target from 2005 Levels	Emission Target ($MtCO_2e$)
Newfoundland and Labrador	25.7%	7.5*
Prince Edward Island	28.6%	1.5*
Nova Scotia	46%	12.53[a]
New Brunswick	47.3%	10.7
Quebec	36.9%	56.1
Ontario	43.9%	114.7
Manitoba	34%	13.7
Saskatchewan	32%	47.2*
Alberta	-16%	270[b]
British Columbia	38.2%	39.5*

* Targets estimated by Boothe and Boudreault (2016)[b]

[a] Nova Scotia's provincial emission target was updated to reflects their business as usual projection. Nova Scotia is the only province which is projected to reduce emissions by more than the provincial targets estimated by Boothe and Boudreault (2016a)

[b] Target calculated based off of Alberta's climate change plan in 2016 by Boothe and Boudreault (2016b)

II) Provincial Indicator Values

Provinces	$MtCO_2e$/Capita	$MtCO_2e$/GDP	GDP/Capita
Newfoundland and Labrador	1.94781E-05	0.00037671	51.55949463
Prince Edward Island	1.22616E-05	0.0003517	34.23411371
Nova Scotia	1.72066E-05	0.000445594	38.32595404
New Brunswick	1.87027E-05	0.000485755	38.32453129
Quebec	9.70333E-06	0.000236658	40.67136111
Ontario	1.20526E-05	0.000248929	47.77079771
Manitoba	1.60568E-05	0.000351755	44.86154313
Saskatchewan	6.63013E-05	0.001193393	54.71530559
Alberta	6.56134E-05	0.000872233	74.17878387
British Columbia	1.29721E-05	0.00026172	48.91446469
Average	2.50348E-05	0.000482445	47.35563498

III) Provincial 2030 Business as Usual Projections

Provinces	Emission Reductions from 2005 Levels	2030 Emissions $MtCO_2e$
Newfoundland and Labrador	5.94%	9.50
Prince Edward Island	24.91%	1.577
Nova Scotia	46.23%	12.474
New Brunswick	33.36%	13.529
Quebec	11.90%	78.32
Ontario	19.28%	164.983
Manitoba	-2.03%	21.018
Saskatchewan	-0.81%	70.06
Alberta	-23.49%	287.492
British Columbia	9.85%	57.609

IV) Allocation Results for Canada's 2030 INDC

Provinces	Equal	Grandfathering	Efficiency	Ability to Pay
Newfoundland and Labrador	21.79561582	23.44021095	19.75413276	22.19477486
Prince Edward Island	36.41496112	41.75421022	33.67891341	33.78938893
Nova Scotia	46.62242337	48.54406247	45.88560724	45.42765421
New Brunswick	46.73455146	48.12085821	46.47286381	45.60069445
Quebec	36.06214114	44.21076197	30.69405906	33.25657404
Ontario	40.33170353	45.3909094	36.2787635	39.31540192
Manitoba	23.1717214	26.58988493	20.57838899	22.33900184
Saskatchewan	24.03789965	16.5200921	32.78997085	22.79768719
Alberta	14.93905274	7.483319435	19.56672667	17.79218249
British Columbia	29.38237452	34.5264623	25.03567217	28.57651043

V) Allocation Results for CAT 2 Degree Target

Provinces	Equal	Grandfathering	Efficiency	Ability to Pay
Newfoundland and Labrador	38.15434372	40.93048725	34.70823719	38.82814042
Prince Edward Island	51.64078389	60.65365374	47.02222395	47.20871112
Nova Scotia	57.94069968	61.18450472	56.69692405	55.92388069
New Brunswick	57.87577423	60.21591646	57.43403481	55.96177742
Quebec	54.06361072	67.81881443	45.00206961	49.32769922
Ontario	55.22287106	63.76301654	48.38134328	53.50731256
Manitoba	39.7828098	45.55280899	35.40515911	38.37714527
Saskatchewan	46.02187975	33.33151453	60.79573226	43.92835062
Alberta	37.42394977	24.83836841	45.23565177	42.24014896
British Columbia	46.36840633	55.05183593	39.03099579	45.00807494

VI) Allocation Results for Canada's 2030 INDC With Alberta at Provincial Emissions Goal

Provinces	Equal	Grandfathering	Efficiency	Ability to Pay
Newfoundland and Labrador	36.00680554	33.51790138	36.15693224	38.86827771
Prince Edward Island	49.64197103	52.64384614	48.3148716	47.27404323
Nova Scotia	56.45486101	55.82733586	57.74428207	55.9683375
New Brunswick	56.41317877	55.08988779	58.49591012	56.00428476
Quebec	51.70041699	57.8134427	46.38817362	49.41024865
Ontario	53.26799102	55.97670033	49.5537938	53.57335839
Manitoba	37.60214229	37.51609758	36.84151851	38.44548719
Saskatchewan	43.13587072	26.20663495	63.50882071	43.98701218
Alberta	-15.97938144	-15.97938144	-15.97938144	-15.97938144
British Columbia	44.13851706	46.35293993	40.38680792	45.08235604

VII) Allocation Results for CAT 2 Degree Target with Alberta at Provincial Emissions Goal

Provinces	Equal	Grandfathering	Efficiency	Ability to Pay
Newfoundland and Labrador	62.70037561	58.46251177	62.95599675	67.62548922
Prince Edward Island	74.4869082	79.59820906	72.22725241	70.44158607
Nova Scotia	74.92360771	73.85511893	77.11910843	74.0959995
New Brunswick	74.59301601	72.33984488	78.13928831	73.89992226
Quebec	81.07455247	91.48321786	72.02938133	77.15164116
Ontario	77.5668501	82.17897677	71.24267646	78.07777002
Manitoba	64.70750493	64.56099639	63.41238877	66.14398589
Saskatchewan	79.00852029	50.1830648	113.6975973	80.51187204
Alberta	-15.97938144	-15.97938144	-15.97938144	-15.97938144
British Columbia	71.85569858	75.62620238	65.46765328	73.45604554

Footnotes

[1] Emissions goals for provinces without established targets were estimated by Boothe and Boudreault (2016a) and supplemented with updated information where applicable. These goals can be viewed in the Appendix I.

[2] Canada's 2030 INDC is considered at 525 $MtCO_2eq$ in the Boothe and Boudreault (2016a) paper.

[3] These studies fall under seven different effort sharing categories namely Responsibility, Capability/Need, Equality, Equal per capita emissions, Responsibility/capability/need, Capability/cost, and staged. These categories are based on the definitions found in the IPCC's Working Group III report (Climate Action Tracker). Included in their selected studies is a study by Climate Analytics (In collaboration with the Climate Action Tracker) using the "PRIMAP Equity tool" which uses a weighted sum distribution with the criterion of Capacity to mitigate, potential to mitigate and historic responsibility to distribute carbon emissions reduction requirements proportionate to a nations share of the global sum of the calculated index. Randomly generated weightings are used to calculate a range of responsibility for this tool.

[4] Yi et al. used weighting scenarios of 0.2+0.2+0.6=1 with one an equal case of 1/3+1/3+1/3=1 while Ringius et al. used various weighting scenarios for their 3 different formulae based on 4 variables totaling to 100.

[5] Torvanger & Ringius (2002) present a good discussion on different national burden sharing proposals as well as a discussion on the Tryptech method.

[6] The use of the outcome based principles "utilitarian", "rawlsian" and "horizontal equity" were also explored.

[7] The efficiency allocation is based on the application of a nationwide carbon tax which allows for transfers

[8] Targets for provinces without established targets were estimated by Boothe and Boudreault (2016a)

[9] The 2 degree target was set as the median of the 2 degree range (318+457)/2 = 387.8. Canada's 2030 INDC target is estimated at 523 $MtCO_2$ as per the Climate Action Tracker's estimate.

[10] The weighting scenarios are (100/3+100/3+100/3=100), and (25+25+55=100). In total there are four scenarios, equal weighting, weighted in favour of CO_2/Capita, weighted in favour of CO_2/GDP, weighted in favour of GDP/Capita.

[11] 2015 is the latest available year for provincial emissions year. All data collections are based on this year as to standardize the data.

[12] The weighting scenarios are as follows (100/3)A+(100/3)B+(100/3)C=100 for the equal weighting scenario and 55A+25.5B+25.5C = 100 for the weighted scenarios. Each criteria is weighted at 55 for its relevant weighted scenario while the other two are weighted equally at 25.5.

[13] CAT does not include LULUCF into their estimates due to the large data inconsistencies associated with LULUCF data, The importance of the need to decrease GHG emissions from combustion, industry, agriculture and waste sources, the need to increase transparency about adequacy of targets, ease of comparison between INDC's without incorporating diverse approaches to LULUCF emissions accounting and methodological constraints due to fair share literature being predominantly based on GHG emissions excluding LULUCF.

[14] Estimates by Boothe and Boudreault (2016a) for the 2030 provincial targets of maritime provinces and British Columbia have been used.

[15] Absolute average difference was calculated by finding the absolute values of change between the provincial targets and the weighting allocations.

[16] This target was generated by taking the median of the upper and lower limits of the Climate Action Tracker's 2-degree scenario for Canada. Referenced in 2018.

[17] Under the sovereignty weighted allocation Saskatchewan retains a surplus emission allocation at 8% above their proposed target.

[18] An equal reduction burden proportional to historic emissions is considered to be an employment of the grandfathering principle and can be seen in (Boehringer) and Ringiusa et al. (1998)