DEVELOPING A REGIONAL CARBON BUDGET FOR METRO VANCOUVER

Sustainability Scholars Program

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DISCLAIMER

This report was produced as part of the UBC Sustainability Scholars Program, a partnership between the University of British Columbia and various local governments and organisations in support of providing graduate students with opportunities to do applied research on projects that advance sustainability across the region.

This project was conducted under the mentorship of Metro Vancouver staff. The opinions and recommendations in this report and any errors are those of the author and do not necessarily reflect the views of Metro Vancouver or the University of British Columbia.

1 Executive Summary

This report is produced as a part of Sustainability Scholars program with Metro Vancouver to develop a carbon budget for the Metro Vancouver region. The average global temperature of the earth has increased by about 1.09°C compared to pre-industrial levels. This has caused unprecedented climate impacts such as increased precipitation and draught periods, ocean acidification and sea level rise, endangering ecological and human systems. Scientists have found a direct relationship between long-lasting greenhouse gases (GHGs) such as carbon dioxide (CO_2) and global temperature rise. Given that, the Intergovernmental Panel on Climate Change (IPCC) has urged nations to work towards limiting global temperature rise to 1.5°C compared to pre-industrial levels.

A carbon budget is the maximum amount of GHGs that can be emitted around the world without increasing the global average temperature by more than 1.5°C. According to the IPCC, that equates to a global carbon budget of 400 gigatonnes with a scenario of limiting global warming to 1.5°C with a 66% likelihood. This report further describes four different methodologies for calculating a carbon budget, one of which is the C40 convergence and contraction methodology. This methodology focuses on equity, responsibility of historic emissions, and capacity to reduce emissions, and has been adopted to develop the carbon budget for Metro Vancouver. According to the convergence and contraction method, Metro Vancouver must reduce emissions to achieve 2.9 tonnes CO_2 equivalent per capita by 2030, as well as to meet the climate targets of 45% reduction from 2010 levels by 2030, and a carbon neutral scenario by 2050, in accordance with the 1.5°C global warming threshold scenario. **The total carbon budget available to Metro Vancouver from 2015 to 2050 is 273.4 Megatonnes ($MtCO_2$).** In order to stay within the 1.5°C threshold and to meet the climate targets, the region would need to stay within the allotted carbon budget and thus future emissions targets would need to be re-evaluated based on available emissions data in previous years so that the budget does not exceed the allocated amount. In order to support this, the 2030 carbon budget that has been established using the convergence and contraction methodology has been made dynamic to adjust for previous emissions and ensure that Metro Vancouver does not exceed its carbon budget.

One of the key recommendations of this report for implementing the carbon budget is to align the carbon budget with the corporate financial budgeting process. This will place importance on the carbon budget when designing policies as well as making decisions for individual projects. The report also recommends adopting a carbon accounting framework to measure emissions and include emission data as an integral part of decision-making. New policies and updates to climate targets should be made to reflect the carbon budget. Finally, findings of Metro Vancouver's Carbon Neutral Scenario modelling can be incorporated into the carbon budget to account for modeled climate action, as well as carbon capture and sequestration.

2 Introduction

In 2011-2020, the average global surface temperature was 1.09°C higher than that in the time period of 1850-1901, with two to three times higher warming in the Arctic (IPCC, 2018). Anthropogenic actions are responsible for 0.8°C to 1.3°C of this global warming (IPCC, 2021). This has contributed to observed precipitation changes, lengthy draughts, observed changes in near-surface ocean salinity, changes in land biosphere, unprecedented glacier melt, and sea level rise.

A carbon budget is the maximum amount of greenhouse gases (GHGs) that can be globally emitted without increasing the global average temperature more than 1.5°C. Carbon dioxide (CO_2) having a near-linear relationship with temperature means that every tonne of CO_2 emitted into the atmosphere results in similar increase in global temperature. Scientists are thus able to make estimates about the cumulative CO_2 that is allowed to be emitted in order to limit global warming to a certain threshold, such as 1.5°C or 2°C. This stresses the importance of a global and regional carbon budget. Having a global carbon budget allows for the allocation of a more localised and detailed budget by various levels of government, and other stakeholders, so that climate targets can be supported. It helps reach climate targets by setting up clear and achievable short-term and long-term emission reduction goals, with a tangible budget to compare progress against in tonnes of CO_2 equivalent. Further, a carbon budget promotes accountability from government and decision-makers to develop clear plans towards emission reduction goals. It also helps evaluate projects with importance to their resulting emissions. Lastly, a uniform scientific measure of allowable emissions increases credibility to set climate targets.

This report provides brief case studies of the carbon budget adopted by the City of Edmonton, as well as City of Oslo, Norway. The final sections of the report present the detailed information on the carbon budget developed for Metro Vancouver and provides key recommendations for consideration in future related work.

3 Background

Through the Climate 2050 (Climate 2050) Strategic Framework, Metro Vancouver has set ambitious, science based climate targets. It aims to achieve carbon neutrality by 2050 with an interim target of 45% reduction from 2010 levels by 2030 (Metro Vancouver, 2018). Metro Vancouver currently is underway to develop Roadmaps for ten key areas that relate to climate action in the Region (i.e. buildings, transportation, industry). The Roadmaps will include strategies, actions and climate policies that will support achieving the Region's climate targets. In addition to Climate 2050, actions and policies to reduce GHG emissions over the next ten years

which support the Climate 2050 Strategic Framework, can also be found in the Region's upcoming Air Quality Management Plan titled the Clean Air Plan. Metro Vancouver recognises that climate change disproportionately impacts low income and marginalised populations (Metro Vancouver, 2021a). Thus, Metro Vancouver aims to focus on fairness, equity, and affordability while also collaborating with a number of key stakeholders in the Region. The carbon budget is developed as a tool for Metro Vancouver to achieve its interim target, as well as long-term climate targets.

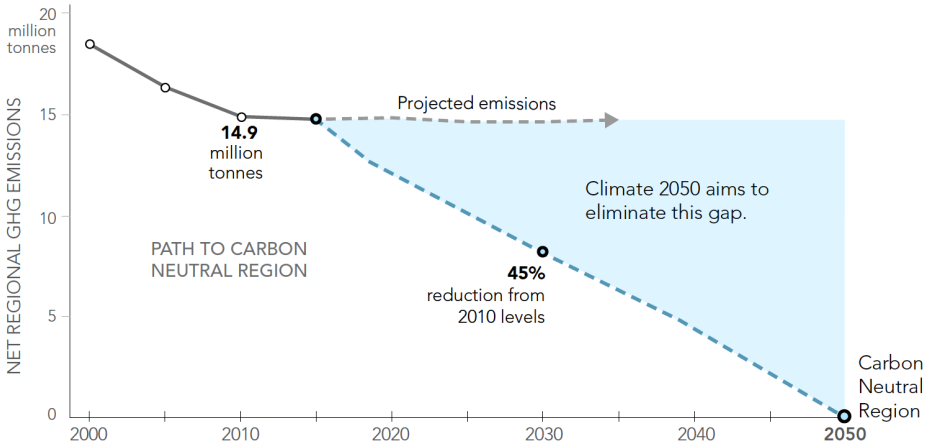

Figure 1 Metro Vancouver Regional Greenhouse Gas emissions Trend
Source: Climate 2050 Strategic Framework, Metro Vancouver, 2018

The objective of this report is to:

1. Present background research on the Intergovernmental Panel on Climate Change (IPCC) global warming targets and the various methodologies for estimating a carbon budget.
2. Describe the methodology used to determine Metro Vancouver's allocation from the total global carbon budget as outlined by the Intergovernmental Panel on Climate Change (IPCC), in order to limit global warming below 1.5 ºC.
3. Present a regional carbon budget for Metro Vancouver that can be used by Metro Vancouver and its member jurisdictions to support climate action.
4. Provide recommendations to Metro Vancouver and its member jurisdictions on how the carbon budget can be used to support climate action in the region and better integrate carbon budgeting as part of key decision frameworks.

4 Literature Review

CO_2 is a long-lived greenhouse gas with a clear direct relationship between anthropogenic emissions and global temperature rise (Allen et al., 2009). Transient Climate Response to Cumulative Emissions (TCRE) is used to express the relationship between CO_2 and global warming. There are also periods of net-negative emissions as well as climate-cooling aerosols that disrupt this relationship and reduce the pace of global temperature increase (Hausfather, 2018; Zickfeld et al., 2016).

The IPCC calculates carbon budgets based on Earth System Models (ESMs). ESMs are complex climate models that simulate carbon and nitrogen cycle, atmospheric chemistry, ocean ecology, and changes in land use, which affect climate response to anthropogenic emissions. ESMs can also

be calibrated to match total past emissions with current observations, after which an estimate can be made of the total allowable emissions that would increase global temperatures by 1.5ºC above pre-industrial levels (Millar et al., 2017). Further studies have modeled additional uncertainties related to earth system feedback processes such as carbon released from production of methane from wetlands and permafrost thawing, into the carbon budget (Lowe & Bernie, 2018). Simple climate models, and observational data on emissions and warming have also been employed to calculate carbon budgets.

City of Amsterdam, Oslo, Edmonton, and the United Kingdom are examples of jurisdictions that have developed and implemented a carbon budget to enable deep emissions reduction. In this report, we will describe the carbon budget for City of Edmonton and Oslo in further detail.

4.1 Global Carbon Budget

In the report released by the Intergovernmental Panel on Climate Change (IPCC) in 2019, anthropogenic global warming of 1.0ºC above pre-industrial levels, under the business as usual scenario, demonstrates that warming is likely to increase temperature by 1.5ºC between 2030 to 2052 (IPCC, 2018). The IPCC has estimated global carbon budgets for a global temperature increase of 1.5ºC, 2ºC, and 3ºC given 33%, 50%, and 66% probability for each. This estimates to approximately 2,900 Gtonnes of GHGs, of which humanity has used about 1,900 Gtonnes between 1870 to 2011 leaving behind a budget of approximately 1,000 Gtonnes from 2011 onwards. In the most conservative scenario of limiting warming to 1.5°C with a 66% likelihood, this global carbon budget is an even smaller 400 Gtonnes (Mcsweeney & Pearce, 2016).

The IPCC Assessment report (AR6) that has been published in August 2021, stresses that global emissions must peak by year 2025 in order to contain global temperature increase to 1.5ºC.

Global warming between 1850–1900 and 2010–2019 *(°C)*	Historical cumulative CO_2 emissions from 1850 to 2019 *($GtCO_2$)*
1.07 (0.8–1.3; *likely* range)	2390 (± 240; *likely* range)

Approximate global warming relative to 1850–1900 until temperature limit *(°C)**(1)	Additional global warming relative to 2010–2019 until temperature limit *(°C)*	Estimated remaining carbon budgets from the beginning of 2020 *($GtCO_2$)* *Likelihood of limiting global warming to temperature limit*(2)*					Variations in reductions in non-CO_2 emissions*(3)
		17%	*33%*	*50%*	*67%*	*83%*	
1.5	0.43	900	650	500	400	300	Higher or lower reductions in accompanying non-CO_2 emissions can increase or decrease the values on the left by 220 $GtCO_2$ or more
1.7	0.63	1450	1050	850	700	550	
2.0	0.93	2300	1700	1350	1150	900	

Figure 2 Estimates of historical CO_2 emissions and remaining carbon budgets. Estimated remaining carbon budgets are calculated from the beginning of 2020 and extend until global net zero CO2 emissions are reached. They refer to CO_2 emissions, while accounting for the global warming effect of on-CO_2 emissions. Global warming in this table refers to human-induced global surface temperature increase, which excludes the impact of natural variability on global temperatures in individual years. Source of table and caption: Intergovernmental Panel on Climate Change, AR6, 2021

Carbon Budgeting Methodologies- Background Research

4.2 CO_2 Induced Global Warming

The CO_2 Induced Global Warming methodology is used to determine carbon budgets that calculate the amount of cumulative carbon emissions that limit global warming to a specific threshold, such as 1.5ºC with a given probability. They assume that CO_2 is the only source of anthropogenic global warming. This budget is calculated using a transient climate response to cumulative emissions of carbon, which is defined as the global average temperature change per unit of cumulative anthropogenic CO_2 emission. CO_2 induced warming may not provide an accurate measure of allowable CO_2 emissions as greenhouse gases other than CO_2 also contribute towards global warming.

4.3 Threshold Exceedance Budgets (TEB)

Threshold exceedance budgets allow the emissions to increase until global temperature rise reaches 1.5ºC and once this temperature is reached, emissions stop immediately (Mcsweeney & Pearce, 2016). The cumulative CO_2 is calculated at this point and that is considered the carbon budget. However, it is not possible to assume emissions will stop immediately once the 1.5 ºC threshold is reached. It also assumes that once emissions stop, there is no further temperature increase. In the TEBs method, all greenhouse gases are considered when calculating 1.5ºC warming and the final carbon budget is expressed in terms of CO_2 equivalent.

4.4 Threshold Avoidance Budgets (TAB)

The threshold avoidance budgets calculate the cumulative carbon emissions that limit global temperature rise to below 1.5ºC with a given probability, as a result of all greenhouse gases (Rogelj et al., 2016). Thus the impact of all greenhouse gasses are taken into consideration at peak global-mean warming, which is an estimate of when CO_2 emissions reach zero allowing time for stabilization of global mean temperatures.

Carbon budgets that account for all greenhouse gas emissions and restrict warming below a certain threshold reflect the most relevant carbon budget based on real-world scenarios.

4.5 Carbon Budget for C40 Cities – Convergence and Contraction

C40 is a cluster of nearly 100 cities around the world making 27% of the global economy and comprises of more than 800 million people. The Convergence and Contraction methodology developed takes into account equity, responsibility, and capacity by allocating a larger portion of the global carbon budget to low GDP/low emission countries and expecting high GDP/high emission countries to reduce emissions significantly. The emission trajectories of both are assumed to converge linearly by 2030 and then decline at a common rate based on the remainder of the global carbon budget. It is a two-phased process developed by the Global Commons Institute to provide a period to adapt to the emission reduction scenarios, until the year of convergence.

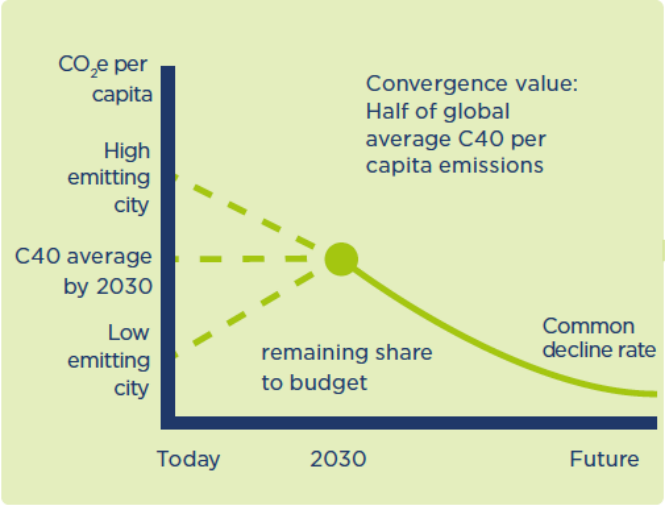

Figure 3 C40 Convergence and Contraction carbon budget methodology.
Source: Deadline 2020, C40 Cities

According to this method, the C40 cities are allotted a carbon budget of 22 GtCO2, or 6% or the global budget until 2100 (C40 Cities & Arup, 2016). The trajectory for emissions reduction for each city is from a set of 4 trajectories, depending on their current emissions per capita and GDP per capita (C40 Cities & Arup, n.d.).

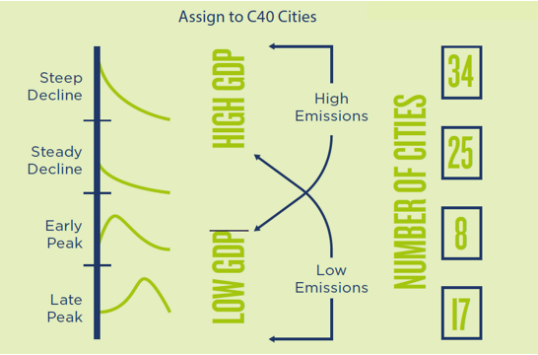

Figure 4 Target trajectories for C40 Cities. One of the four target trajectory is assigned to each C40 city, based on current emissions and GDP per capita.
Source: Deadline 2020, C40 Cities

This methodology is aimed at limiting the global temperature rise to 1.5 degrees with a 66% probability.

A limitation of the contraction and convergence method is the assumption that low GDP and low emitting cities will have a turning point in 2030 and be able to start reducing their emissions henceforth.

5 Case Studies

5.1 City of Edmonton

The City of Edmonton developed a local carbon budget as part of Edmonton's Community Energy Transition Strategy to align their emission targets and climate actions. Edmonton calculated the carbon budget using the C40 methodology and have 155 Mt in the Cities' allocated carbon budget to be used between 2019 and 2050. Their 2030 estimates were set to 3.2 tonnes per person in accordance with the C40 convergence and contraction methodology.

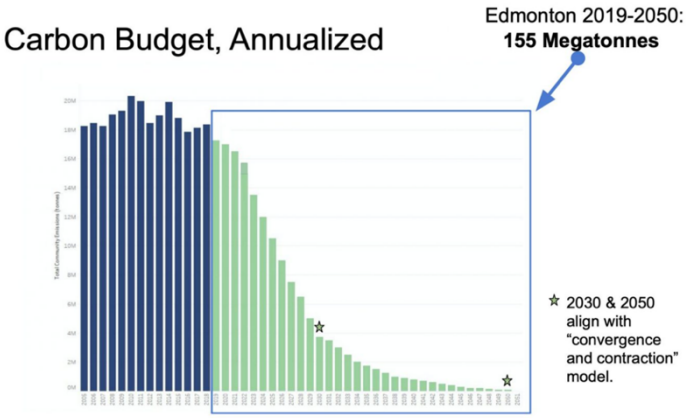

Figure 5 Carbon Budget developed by the City of Edmonton as part of their Community Energy Transition Strategy to stay within the 1.5°C temperature rise limit.
Source: City of Edmonton, Carbon Budget and Accounting Information Brief, 2019

A five-step framework based on carbon accounting is designed to guide decision making by the City of Edmonton (Charles, 2020).

1. **Identify the project**: The new carbon budget may be focused on projects under the Community energy transition strategy, Civic Operations, Greenhouse Gas Management Plan, and other city departments.
2. **Analyse its greenhouse gas impacts**: Calculate how much carbon the city is allocated to emit using a carbon accounting tool.
3. **Prioritization**: ensuring emissions goals take precedence in decision-making by aligning the carbon budget with the corporate financial budget.
4. **Identify carbon deficit**: Report findings to city council and host a public hearing. In case of a deficit in the carbon budget, the decision to approve or reject the project lies with the council.
5. **Evaluate impact of the project:** improve forecasts by evaluating impacts using annual inventories.

As part of developing a carbon budget for Metro Vancouver, we conducted a semi-structured interview with City of Edmonton to learn about their methodology and recommendations for implementing the carbon budget. Some of the key lessons learned and recommendations from the City of Edmonton are:

1. Understanding the carbon footprint of corporate activities in the city through a carbon accounting framework. A carbon accounting framework enables the city to estimate GHG emissions and reductions from projects and actions in the city using consistent formulas.
2. Aligning carbon budget with the corporate financial budget process. This would ensure that emission goals and climate action takes precedence in the decision-making process. These estimates can then be incorporated into initial proposals and status reporting.
3. City of Edmonton also emphasised that carbon budgeting is an iterative process with multi-step implementation. The carbon budget should be a guide to emissions reduction actions.
4. Setting up a carbon budget office responsible for carbon budgeting can provide leadership for training, education, and capacity building in the organisation. This office could be placed in the financial accounting department of the City, who are currently leading the implementation of the carbon budget due to expertise and in an effort to streamline the process.

5.2 City of Oslo

Oslo adopted a carbon budget in 2016 as an important governance tool to help achieve their climate and energy strategy targets. The carbon budget aims to reduce Oslo's CO_2 emissions by 36% by 2020, 50% by 2022, and 95% by 2030 compared to 1990 levels. It was carried out in two steps: the first-generation included 42 climate measures targeted at energy, buildings, resources, and transport; the second generation consisted of a revised carbon budget accounting for carbon capture and storage, 36 climate measures, and emphasised the need to integrate the carbon budget in to the City's regular budget processes. The second-generation carbon budget will help Oslo reduce its CO_2 emissions by 460,000 tonnes by 2020 compared to 2015 levels (European Green Capital, 2018).

The steps taken by Oslo in successfully developing a carbon budget are (European Green Capital, 2018):

1. **Governance and commitment:** The Department of Finance and City Council for Environment and Transportation are accountable for the carbon budget, while the city council oversees the implementation and monitoring of climate actions.
2. **Communication and collaboration:** communication, involvement, and engagement of

Figure 6 City of Oslos' historical GHG emissions, BAU 2020 and carbon budget projections to 2030, as well as 2020 and 2023 annual GHG emissions caps. Source: City of Oslo, Technical Presentation of the Oslo Climate Budget, Sept, 2020

the various stakeholders (general population, business communities, NGOs, and city agencies) is important in achieving climate targets set by the carbon budget.

3. **Target measures:** Offices responsible for implementing climate targets will have prioritised emissions reduction goals along with regular progress reporting.
4. **Regulatory enforcement:** Oslo recognises that managing laws and regulations regarding climate and environment are vital to the success of the carbon budget.
5. **Transparency:** Having a transparent climate budget makes it easier to understand as well as builds trust in the overall process.
6. **Reporting:** Statistics Norway records the emissions statistics, along with supplementary data from other sources, used to achieve Oslo's Climate Budget. The Climate Budget measures are reported in the Oslo Municipality.

The City of Oslo identified the contribution of major sectors to regional emissions between 2009 to 2018 and set goals for GHG emissions reductions between 2017 to 2030 for each of the sectors. Oslo plans to achieve the set GHG emissions reduction by implementing a regular budget reporting process and recognising key performance indicators. The carbon budget treats the city's CO_2 emissions similar to it's financial budget.

5.3 Carbon Budget for Metro Vancouver

The carbon budget for Metro Vancouver was determined using the C40 convergence and contraction methodology. This method was chosen as it is a widely accepted method for calculating the carbon budget. This methodology takes into account equity, capacity and responsibility towards reducing emissions by different cities around the world.
The development of a regional carbon budget for Metro Vancouver was conducted as a part of the Sustainability Scholars project with Metro Vancouver.

The first step was conducting a literature review on carbon budgeting, and background research about the different methodologies for calculating the carbon budget for a region. Following this, the convergence and contraction methodology created and adopted by the C40 Cities was deemed most appropriate for developing a carbon budget for Metro Vancouver as it is a credible, and equitable way to allocate carbon budget, and has been developed specifically for the local government context. This method has been recognised as a feasible way to share responsibility with a consideration of equity. It has also been adopted by the United Kingdom as well as the City of Edmonton to develop their national and municipal carbon budgets respectively.

The C40 convergence and contraction methodology allocates 3.2 tonnes per person of emissions for the year 2030 and net zero emissions by 2050 for a global temperature increase scenario of 2^{o}C. Whereas, it allocates 2.9 tonnes per person of emissions for the year 2030 and net zero emissions by 2050 for a global temperature increase scenario of 1.5^{o}C (C40 Cities & Arup, n.d.). Using these reference points, the carbon budget calculated for Metro Vancouver is 273.4 $MtCO_2$

between 2015 and 2050. The emissions inventory maintained by Metro Vancouver consists of estimated emissions that to date have been calculated to 2015 and include projected emissions until 2035. The emissions inventory is updated every five years, however more frequent annual reporting is anticipated moving forward. In order to calculate the carbon budget for Metro Vancouver, the CO_2 equivalent for 2015 was used as the baseline.

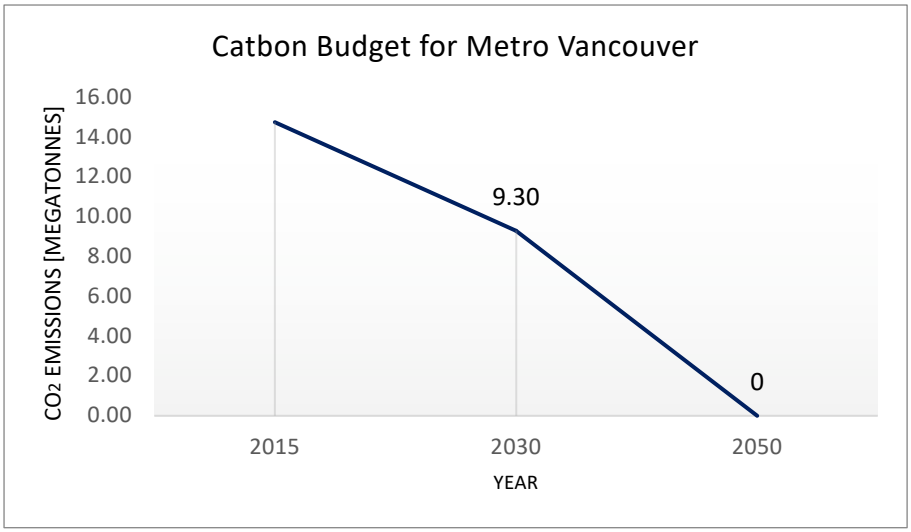

Figure 7 Carbon budget for Metro Vancouver from 2015 to 2050 calculated according to C40 contraction and convergence methodology to stay within 1.5°C temperature rise with 66% probability.

Metro Vancouver's Climate 2050 Strategic Framework has set targets of 45% greenhouse gas emission reduction from 2010 levels by 2030 and carbon neutrality by 2050. Figure 8 shows a comparison between the carbon budget and Metro Vancouver's Climate 2050 Strategic Framework targets.

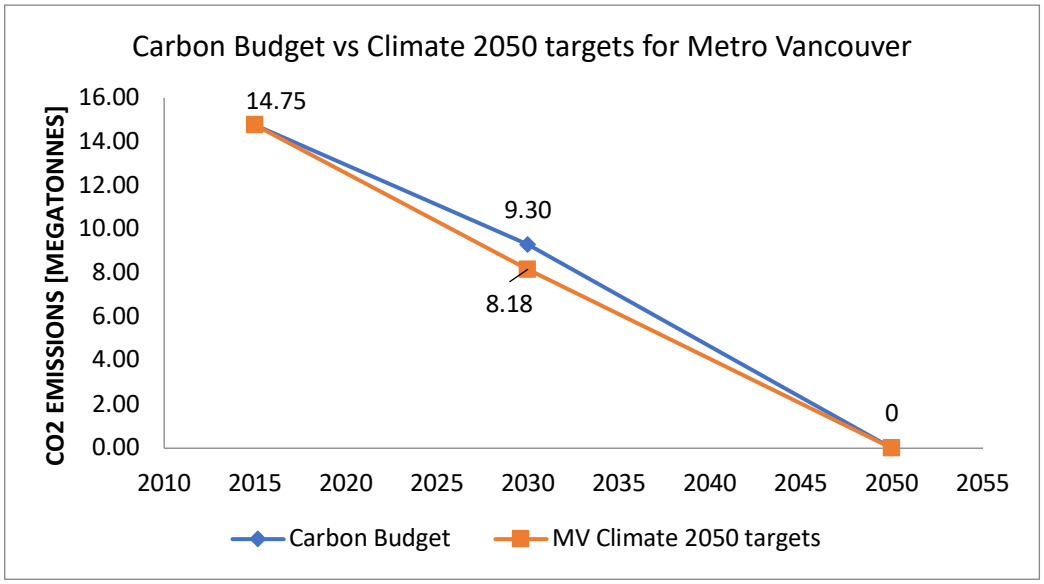

Figure 8 Comparison between calculated carbon budget for Metro Vancouver and its Climate 2050 targets. The blue line shows the emissions trajectory for maximum allowable carbon emissions to remain within the set carbon budget. The orange line corresponds to emissions targets set by Metro Vancouver's Climate 2050 Strategic Framework.

It is important to note that this graph assumes a linear trajectory between 2015 to 2030, and 2030 to 2050, which may not be the same as real-world emissions trajectories. Further, the 2030 carbon budget value for Metro Vancouver is based on the C40 target of 2.9 tCO_2 per person emission. However, the next section shows how in the event that Metro Vancouver exceeds its yearly emissions targets, the 2030 emissions target will be adjusted accordingly to ensure that the carbon budget is not exceeded. This would in-turn close the gap between the carbon budget emissions modeling and the emissions modeling based on Metro Vancouver's Climate 2050 Strategic Framework. Finally, upcoming IPCC reports and recommendations are expected to strive for more ambitious climate targets to contain global temperature increase to 1.5°C. This should further be reflected in updates made to Metro Vancouver's carbon budget.

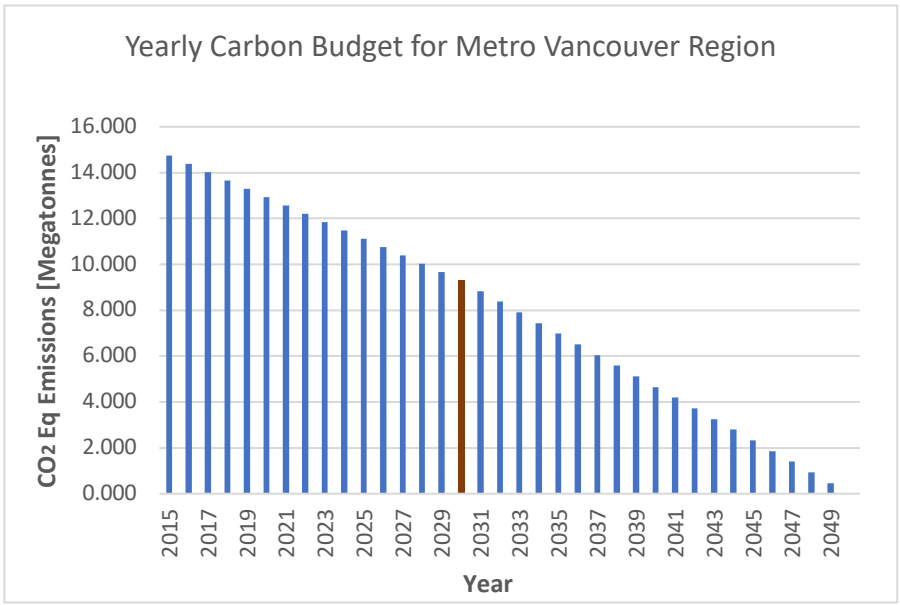

Figure 9 Yearly breakdown of carbon budget for Metro Vancouver between 2015 to 2050

The carbon budget needs to be adaptive, to account for the annual emissions data for Metro Vancouver, so that the remaining budget and emissions targets can be adjusted accordingly. For example, if the GHG emissions calculated in 2020 for Metro Vancouver is higher than that required to stay within the carbon budget trajectory shown in Figure 7, in such a case where Metro Vancouver emits more than the set target, Metro Vancouver would need to aim for steeper reductions in the following years to remain within the carbon budget. Thus the carbon budget needs to be annually updated to be adjusted as required based on the available emissions data from the previous year. To do this, the 2030 target of 2.9 tonnes per person set by C40 cities has been made dynamic in the carbon budgeting tool. Adjusting the yearly carbon budget based on available emissions data will accordingly adjust future emissions targets for Metro Vancouver to stay within the allotted carbon budget.

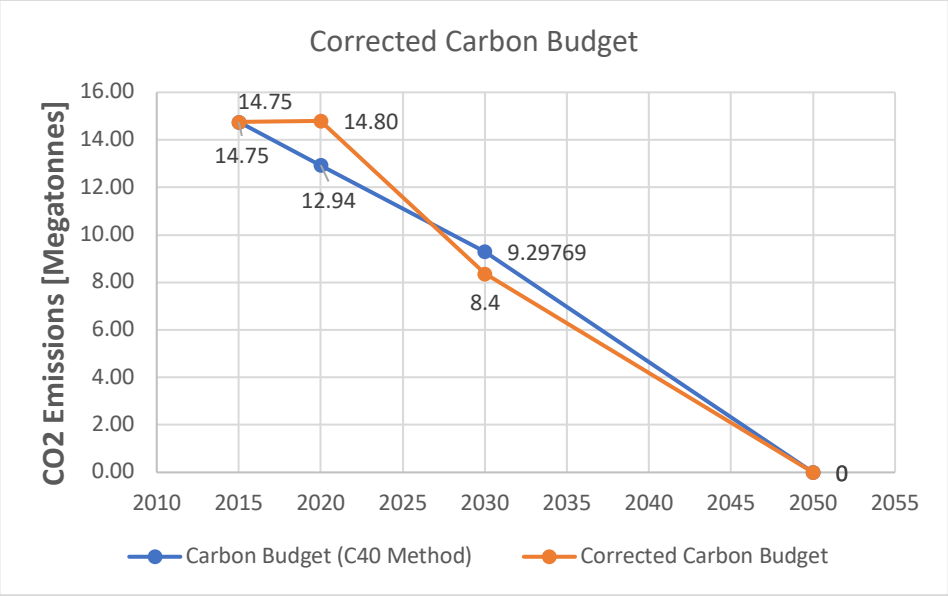

Figure 10 In this figure you can see how the Carbon budget for Metro Vancouver has been made dynamic. Blue line shows the most recent carbon budget as calculated in 2021, using estimated 2015 emissions data. The orange line shows how the carbon budget should be corrected if 2020 estimated emissions exceed allowable emissions by the blue carbon budget line.

In Figure 10, you can see how the Carbon budget for Metro Vancouver has been made dynamic. The blue line shows the most recent carbon budget as calculated in 2021 for this report, using estimated 2015 emissions data. The orange line shows how the carbon budget should be corrected if 2020 estimated emissions exceed allowable emissions for 2020, as shown by the blue carbon budget line. The current orange line is based on 2020 forecast emissions taken from the emissions inventory of Metro Vancouver.

Figure 10 shows the corrected carbon budget based on the projected, estimated emissions for 2020 as modeled in Metro Vancouver's emissions inventory. This reduces the allowable emissions for year 2030, from 10.26 Megatonnes to 9.5 Megatonnes. This also shows that according to the business as planned (BAP) scenario based on projected emissions modeled currently in the

emissions inventory, Metro Vancouver would have to set steeper climate targets to make up for additional emissions in the previous years in order to remain within the set carbon budget. However, with continued and strengthened implementation of climate action, the targets would not have to be as steep year to year in a carbon neutral modeling scenario. This stresses the importance of Metro Vancouver to continue in currently established efforts to reduce greenhouse gas emissions, and continuing to expand and strengthen efforts to reduce emissions along side other relevant stakeholders in the region, through implementation of actions and policies in Metro Vancouver's Climate 2050 Strategic Framework and Roadmaps, as well as the Clean Air Plan[2][3].

6 Recommendations for Using the Carbon Budget

The carbon budget for Metro Vancouver is developed to be dynamic, such that it will adjust the allowable emissions for the future years depending on recorded emissions in the previous years. This is done so that the total carbon budget is not exceeded due to carbon emissions used in previous years.

The following outlines some of the recommendations to Metro Vancouver on how the outcomes of estimating a carbon budget can be used for decision making and climate action:

- Align the carbon budget with the corporate financial budgeting process. This will place precedence on the carbon budget when designing policies as well as making decisions for individual projects. A project or plan must be modified to reduce its carbon footprint as required, to stay within the carbon budgets. This accounting process can be streamlined if the financial department of corporate is in charge of both the financial and corporate accounting.
- Make carbon budget an integral part of decision-making. New policies and updates to climate targets should be made to reflect the carbon budget. This can be done by implementing a carbon accounting framework, as done by the City of Edmonton.
- Metro Vancouver should make the required adjustments to its carbon budget according to any changes in science, and/or updated IPCC targets. These adjustments can be made directly in the excel toolkit.

Carbon accounting framework is understood by scientists as the process of making scientifically robust GHG emission measurements and to policy-makers it is a way to incorporate these emissions into decision-making (Ascui & Lovell, 2011). A carbon accounting framework enables decision-making based on an organisation or region's carbon footprint. There are software developed to support organisations with making decisions based on their carbon footprint (Charles, 2020). Metro Vancouver can look into such software developed to calculate and assess their carbon

[2] http://www.metrovancouver.org/services/air-quality/AirQualityPublications/Clean-Air-Plan-2021.pdf
[3] http://www.metrovancouver.org/services/air-quality/AirQualityPublications/AQ_C2050-StrategicFramework.pdf

footprint related to business processes and projects. Section 5.1 explains how the City of Edmonton has used the carbon accounting framework to incorporate the carbon budget into their decision-making process.

The IPCC established guidelines regarding carbon accounting framework which consists of importance on transparency, completeness, consistency, comparability, and accuracy.

Steps to improve the carbon budget:

- The current carbon budget for Metro Vancouver has been developed based on its emissions inventory. It would be integral to incorporate the Carbon Neutral Modelling scenario into the carbon budget (Metro Vancouver, 2021b). This would help model planned emission reduction actions and evaluate their impact. It would also take into consideration carbon capture and sequestration that contribute to negative emissions. This would help align the different climate targets for Metro Vancouver and make for robust policies.
- Future research related to the carbon budget can be strengthened by looking into integration of the carbon budget with the financial department. Further efforts into understanding the steps required and challenges with streamlining the carbon and financial budget would be instrumental to the successful implementation of the carbon budget.
- Allocate portions of the carbon budget to each sector contributing to GHG emissions in Metro Vancouver based on their total emissions and capacity to reduce emissions.
- A high-level recommendation, for a federal framework on developing and implementing a regional carbon budget, as it would provide uniformity, a fair comparative analysis between jurisdictions in Canada, and ensure the use of similar methodology allowing data to be easily aggregated at a national level.

References

Allen, M. R., Frame, D. J., Huntingford, C., Jones, C. D., Lowe, J. A., Meinshausen, M., & Meinshausen, N. (2009). Warming caused by cumulative carbon emissions towards the trillionth tonne. *Nature*, *458*(7242), 1163–1166. https://doi.org/10.1038/nature08019

Ascui, F., & Lovell, H. (2011). As frames collide: Making sense of carbon accounting. *Accounting, Auditing & Accountability Journal*, *24*(8), 978–999. https://doi.org/10.1108/09513571111184724

C40 Cities, & Arup. (n.d.). *Deadline 2020*. https://www.c40.org/researches/deadline-2020

C40 Cities, & Arup. (2016). *Deadline 2020 Methodology*. https://c40-production-images.s3.amazonaws.com/other_uploads/images/954_Deadline_2020_Methodology_%281%29.original.pdf?1480603800

Charles, C. (2020, October). Webinar Recap: Creating a Carbon Budget. *Sustainable Waterloo Region*. https://www.sustainablewaterlooregion.ca/2020/10/14/webinar-recap-creating-a-carbon-budget/

European Green Capital. (2018). *Oslo_Climate_Budget* (p. 2). https://ec.europa.eu/environment/europeangreencapital/wp-content/uploads/2018/05/Oslo_Climate_Budget.pdf

Hausfather, Z. (2018, April 9). *Analysis: How much 'carbon budget' is left to limit global warming to 1.5C?* Carbon Brief. https://www.carbonbrief.org/analysis-how-much-carbon-budget-is-left-to-limit-global-warming-to-1-5c

IPCC AR6 WGI. (2021). *Climate Change 2021—Physical Science Basics—Summary for Policymakers—Sixth Assessment Report*. https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf

Lowe, J. A., & Bernie, D. (2018). The impact of Earth system feedbacks on carbon budgets and climate response. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *376*(2119), 20170263. https://doi.org/10.1098/rsta.2017.0263

Mcsweeney, R., & Pearce, R. (2016, May 19). *Analysis: Only five years left before 1.5C carbon budget is blown*. Carbon Brief. https://www.carbonbrief.org/analysis-only-five-years-left-before-one-point-five-c-budget-is-blown

Metro Vancouver. (2018). *Climate 2050 Strategic Framework*. http://www.metrovancouver.org/services/air-quality/AirQualityPublications/AQ_C2050-StrategicFramework.pdf

Metro Vancouver. (2021a). *Clean Air Plan, 2021*. http://www.metrovancouver.org/services/air-quality/AirQualityPublications/Clean-Air-Plan-2021.pdf

Metro Vancouver. (2021b). *Carbon Neutral 2050 Policy & Modelling Report* (p. 97). http://www.metrovancouver.org/services/air-quality/AirQualityPublications/LGEO_MV_CNS_ModelingReport_July2021.pdf#search=%22carbon%20neutral%20modeling%22

Millar, R. J., Fuglestvedt, J. S., Friedlingstein, P., Rogelj, J., Grubb, M. J., Matthews, H. D., Skeie, R. B., Forster, P. M., Frame, D. J., & Allen, M. R. (2017). Emission budgets and pathways consistent with limiting warming to 1.5 °C. *Nature Geoscience*, *10*(10), 741–747. https://doi.org/10.1038/ngeo3031

Rogelj, J., Schaeffer, M., Friedlingstein, P., Gillett, N. P., Vuuren, D. P. van, Riahi, K., Allen, M., & Knutti, R. (2016). Differences between carbon budget estimates unravelled. *Nature Climate Change*, *6*(3), 245–252. https://doi.org/10.1038/nclimate2868

Zickfeld, K., MacDougall, A. H., & Matthews, H. D. (2016). On the proportionality between global temperature change and cumulative CO 2 emissions during periods of net negative CO 2 emissions. *Environmental Research Letters*, *11*(5), 055006. https://doi.org/10.1088/1748-9326/11/5/055006