Research Paper

Measuring the environmental sustainability performance of the supply chain of BC's utility sector for carbon, sulfur dioxide, and water footprints

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Abstract

This research paper provides a comprehensive analysis of the environmental sustainability performance of the supply chain in British Columbia's utility sector, with a focus on carbon, sulfur dioxide, and water footprints. It utilizes a rigorous methodology, including a literature review, data analysis, and software tools, to offer valuable insights. The study adopts an input-output framework and relies on reliable government data sources. The analysis uncovers variations in performance across different indicators, highlighting the electricity sector's relatively lower greenhouse gas emissions compared to other sectors. Notably, the natural gas sector has made progress in mitigating emissions by targeting methane reduction measures. However, challenges in measuring water footprints are identified due to data gaps and inconsistencies.

The study also recognizes limitations in its assumptions and the need to incorporate qualitative analysis to complement the quantitative assessment. It acknowledges potential inaccuracies in government data sources and the study's limited scope, which solely focuses on BC's utility sector. Furthermore, the research acknowledges the simplifications inherent in the input-output framework and the absence of future projections or scenarios. To address these limitations and enhance sustainability performance, the paper offers relevant recommendations. These include strengthening renewable energy sources, reducing methane emissions, promoting energy efficiency, supporting low-carbon transportation, fostering collaboration, implementing robust monitoring, and reporting systems, improving data collection, integrating qualitative analysis, considering future projections, enhancing model validity, and expanding the study's scope.

By considering these recommendations in future research, this study aims to overcome limitations and provide a more comprehensive assessment of the environmental sustainability performance within BC's utility sector. The findings hold practical implications for policymakers, industry stakeholders, and researchers seeking to drive supply chain sustainability in the utility sector, particularly regarding carbon, sulfur dioxide, and water footprints.

Keywords: Supply Chain, Sustainability Assessment, Industry Level, Utility, Natural Gas, Electricity, Oil and Gas Transmission, Input-Output Analysis.

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List of Abbreviations

BC	British Columbia
CO2	Carbon Dioxide
CO2e	Carbon Dioxide Equivalent
GHG	Green House Gas
IO	Tables Input Output Tables
MtCO2e	Metric Tons of Carbon Dioxide Equivalent
SO2	Sulphur Dioxide

1. Introduction

With globalization and advancement in communication and transportation technologies, supply chain sustainability has become an essential issue for businesses around the World (Hahn et al., 2015). The problems in supply chain sustainability refer to integrating economic, social, and environmental concerns into all aspects of the supply chain, from sourcing raw materials to delivering the finished goods to customers (Seuring, 2013). It is essential to advocate a sustainable supply chain as it balances the interest of all the stakeholders, including employees, suppliers, customers, and shareholders (Carter and Rogers, 2008). Advocacy of sustainable supply chain management can lead to the creation of competitive advantage through the integration of information flow and resource transformation within a framework of activities, as elaborated by Seuring and Müller (2008) and further explained by Crum et al. (2011) and Ageron et al. (2012). Supply chain sustainability is also important from the environmental perspective as it can help to reduce the negative impact of business activities on the environment. Integrating environmental concerns in supply chain activities can improve greenhouse gas (GHG) emissions, reduce the wastage of resources, and promote the sustainable use of natural resources (Seuring, 2013). In this paper, Sustainable supply chain management, sometimes called green supply chain management, refers to integrating environmental thinking into the lifecycle of supply chain activities (Acquaye et al., 2017).

Although measuring supply chain management performance is crucial for shifting the operational functions towards a sustainable supply chain (Yang et al., 2011), measuring the environmental impact of a product, service, or process across the entire supply chain is always challenging. Various reach works have addressed this challenge, including Lehtinen and Ahola (2010) and Hassini et al. (2012). These challenges can be attributed to conflicting measures that characterize the performance of the supply chain (Liang et al., 2006), focus on implementation rather than performance outcomes for green supply chain management (Zhu et al., 2008), the extensively dynamic nature of the supply chain (Gunasekaran et al., 2004), and multifaceted nature of environmental issues (Hubbard, 2009). In addition to these attributes, the research for this topic is motivated by the fact that industry-related emissions of greenhouse gases (GHG) have increased and are higher than other end-user sectors (Fischedick et al., 2014).

The utility sector contains some of the crucial industries that can strongly impact a country's economic growth. However, at the same time, the utility sector is one of the major consumers of natural resources (direct and indirect) and a source of several environmental emissions. That is why sustainable supply chain performance in the utility sector is essential and requires continuous assessments and improvements to reduce its environmental impact. Considering all these aspects, this research aims to measure the environmental sustainability performance of the supply chain of British Columbia's (BC) utility sector, specifically focusing on the carbon, sulfur dioxide, and water footprints. Sustainability has been widely discussed in various literatures, and United Nations (UN) defined it as "meeting the needs of the present without compromising the ability of the future generation to meet their own needs" (World Commission on Environment and Development, 1987). The sustainability performance of the supply chain can be assessed on various environmental indicators such as air pollution, water consumption, and greenhouse gases (GHG). Therefore, measuring the environmental sustainability performance of the utility sector's supply chain in BC will provide a comprehensive understanding of its environmental impact and highlight improvement areas. Carbon dioxide, sulfur dioxide, and water footprints are the three primary indicators used for this study. The carbon footprint measures the total carbon dioxide emissions due to the supply chain activities of the utility sector of BC, including direct and indirect emissions. Sulfur dioxide footprints measure the sulfur dioxide emissions from the supply chain, significantly contributing to air pollution and acidic rains. Finally, the water footprint measures the total amount of freshwater consumed by the supply chain activities, including the extraction, processing, and disposal of products and services. These three significant emissions are selected because they represent different environmental sustainability dimensions of climate change, pollution, and resource extractions (Acquaye et al., 2017) and are also aligned with the United Nation's Sustainable Development Framework (United Nations, 2015).

This paper analyzes the sustainability of the supply chain of the utility sector of British Columbia in Canada using the IO analysis method for the year 2019 (Kjær et al., 2015 Acquaye et al., 2017). The paper considers Oil and Gas, Electric Power Generation and Transmission, Natural Gas Distribution, and Pipeline Transportation industries as components of the utility sector in BC, Canada. The analysis was carried out based on the Input-Output tables provided by the Government of Canada on its official website (Statistic Canada, 2019). The paper also considers the BC GHG emissions report 1990-2020 (Government of BC, 2020) and sulfur dioxide emission (Government of Canada, 2021) for the calculations to carry out the Input-Output Analysis. Environmental input-output analysis is a promising tool for achieving environmental assessments, including the supply chain's impact (Larsen, Solli, & Pettersena, 2012; Wiedmann, 2009). The outcomes and findings of this research paper can guide the calculation of sustainability performance within the supply chain of industries in the utility sector of British Columbia. This research paper's outcomes and findings can guide sustainability performance calculations in the utility sector supply chain of British Columbia. They offer insights to enhance sustainability practices in other regional industries, inform government policy decisions, and serve as a resource for future research on sustainability in supply chains.

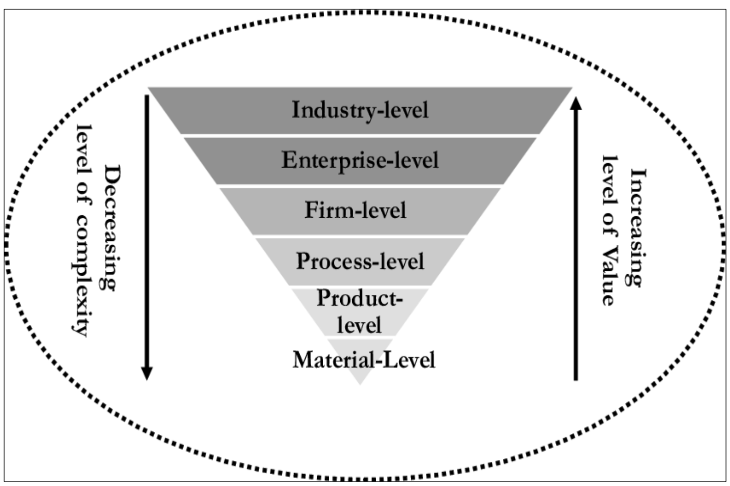
2. Literature Review

2.1 Industries as a part of the value chain

A supply chain can be defined as a series of value-added activities by integrating information and resource flows. Horvath (2001) suggested a similar contemporary view of the supply chain, which he defines as a network of multiple relationships for value addition. Min and Zhou (2002) and Kemppainen and Vepsäläinen (2003) presented a similar rationale schematically in Figure 1.

Figure 1

The complexity of supply chain systems – a hierarchical perspective of the value chain



Note. Complexity of supply chain systems – a hierarchical perspective of the value chain. Adapted from "Measuring the Environmental Sustainability Performance of Global Supply Chains: A Multi-Regional Input-Output analysis for Carbon, Sulphur Oxide and Water Footprints" by Acquaye et al. (2016), Journal of Environmental Management, 187. https://doi.org/10.1016/j.jenvman.2016.10.059

The literature on industrial clusters within global value chains has emphasized the significance of inter-firm cooperation in enhancing cluster performance (Humphrey and Schmitz, 2008; Pietrobelli and Rabellotti, 2011; Gereffi and Lee, 2016). Collaboration among firms within a cluster is known to foster productivity, innovation, and competitiveness. However, when assessing the environmental performance of regional value chains, a firm-based view or bottom-up perspective alone is insufficient (Saliola and Zanfei, 2009). While examining individual firm actions is valuable, it fails to capture the broader industry-level environmental impact and sustainability. To address this limitation, this paper argues for adopting a top-down industry-level perspective when analyzing and measuring the environmental sustainability of global value chains. The paper tries to propose a shift in focus from the firm level to the industry level, which indeed can be a more comprehensive approach to understanding the collective environmental effects of multiple firms within the same sector. An industry-level approach enables the identification of systemic patterns, common challenges, and potential solutions to improve environmental performance and sustainability. It provides insights into how different firms within the value chain contribute to environmental issues, such as greenhouse gas emissions, resource depletion, and pollution.

2.2 Measurement of environmental sustainability

Given the increasing recognition of the importance of sustainability in business practices, sustainable supply chain management has emerged as a critical aspect of the operations function (Dey et al., 2011; Hassini et al., 2012). An important component of environmentally sustainable supply chain management is the direct link between accounting approaches and their application to production and supply chain networks to measure sustainability performance. The literature has extensively examined this link, exploring key themes such as models and methods for measuring sustainability performance (Brandenburg et al., 2014), the integration of social, environmental, technological, political, and economic performance issues (Schaltegger and Burritt, 2014), and reporting on sustainability performance (Lodhia and Hess, 2014). These studies provide insight into the practical challenges and opportunities of implementing sustainable supply chain management practices. They highlight the importance of measuring and reporting sustainability performance metrics and integrating social and environmental considerations into the supply chain management decision-making processes. Overall, the literature on sustainable supply chain management underscores the need for a comprehensive and integrated approach to managing environmental sustainability in the supply chain. It highlights the critical role of accounting and measurement approaches in implementing sustainable practices and emphasizes the importance of considering social, environmental, technological, political, and economic performance issues in pursuing sustainability.

The growing focus on sustainability has prompted increased attention toward lifecycle thinking. Lifecycle assessment, which serves as the foundation for environmental performance measurements at the product level (Heijungs et al., 2010), can also be extended to the industry level (Joshi, 1999). This approach aligns with the principles of the Greenhouse Gas Protocol and emphasizes considering all supply chain activities throughout the production and consumption processes. Lifecycle thinking encompasses all production and supply chain stages, including raw material extraction, processing, transportation, and value-added activities. It offers benefits at the product level, such as identifying carbon hotspots and mapping the supply chain (Koh et al., 2013). However, this bottom-up approach has limitations, including truncation error (Feng et al., 2014a) and challenges associated with scaling up the value chain from the product level. The existing literature acknowledges the extensive assessment of bottom-up approaches, particularly at the product level, as demonstrated by Glew and Lovett (2014), Koh et al. (2013), and Smith (2012). However, it is worth noting that research studies from practitioners and academia in this area generally lack a strong theoretical foundation and methodological robustness. Examples of practitioner-oriented studies include the Network for Business Sustainability (2012), Sustainalytics (2011), and the Mineral Products Association (2013). Academic works such as

Bassioni et al. (2004), Yongvanich and Guthrie (2005), and Singh et al. (2007) also highlight the scarcity of rigorous theoretical and methodological frameworks in this field. Additionally, it can be difficult to measure the effectiveness of sector-specific policies.

The paper proposes adopting an industry-level perspective when measuring environmental performance to address these limitations. An industry-level approach provides a more holistic view of value chains and allows for the assessment of overall industry performance. It enables the evaluation of policy effectiveness within specific industries, identifying opportunities for improvement. In summary, lifecycle thinking and environmental performance measurement at the industry level offer a more comprehensive and holistic perspective on sustainability within value chains. By considering the overall performance of specific industries, evaluating policy effectiveness, and enabling industry comparisons, this approach supports the advancement of sustainable practices and performance improvement.

Environmental performance measurements serve two primary objectives. Firstly, they aim to establish the link between environmental systems and business operations, particularly in the context of environmental sustainability reporting (Melnyk et al., 2003; Clarkson et al., 2011). This involves measuring and reporting on various environmental indicators to provide transparency and accountability regarding environmental impacts. Secondly, environmental performance measurements strive to integrate environmental management with business and competitive strategies (Porter and Kramer, 2006; Hart and Milstein, 2003; Wagner and Schaltegger, 2003). By aligning environmental objectives with overall business goals, organizations can enhance their competitiveness, achieve cost savings through resource efficiency, and respond to the growing expectations of environmentally conscious stakeholders. To achieve these outcomes, it is crucial to employ appropriate analytical frameworks for model development and utilize the generated results to inform supply chain management practices.

However, studies focusing on this specific area are lacking. Recent works have emphasized the need for further research in sustainable supply chain performance measurement. Taticchi et al. (2013) highlight that while the field is growing rapidly, it is still considered relatively immature. Schaltegger and Burritt (2014) also note a lack of research on sustainability performance issues, including methods for measuring and managing sustainable supply chains.

This paper aims to contribute to the advancement of knowledge in this area by presenting new developments, practical applications, and implications. By addressing the gaps identified in the existing literature, the research seeks to enhance the understanding and implementation of sustainable supply chain performance measurements. Through these contributions, it is anticipated that the organizations in British Columbia, Canada, will be better equipped to design and manage sustainable supply chains, aligning environmental objectives with business strategies and fostering long-term environmental sustainability.

A review of extant literature suggests that there are generally two research pathways commonly used in studies related to sustainability performance measurement. One pathway focuses on developing sustainability indicators and identifying key performance drivers (Epstein and Roy, 2001; Bohringer and Jochem, 2007; Hezri and Dovers, 2006; Singh et al., 2007; Shaw et al., 2010). The second pathway involves measuring sustainability performance using different frameworks and approaches (Dias-Sardinha and Reijnders, 2001; Hubbard, 2009). Methodologies used to measure sustainability performance are often based on the principles of lifecycle assessment (LCA) (Kissinger et al., 2011; Lake et al., 2014). Current LCA methodologies suggest that models developed using the input-output framework provide a systematic assessment approach with an extended system boundary, enabling comprehensive evaluation of direct and indirect environmental impacts associated with activities (Wiedmann and Minx, 2007; Suh & Kagawa, 2005; Kumar et al., 2014). Direct environmental impacts refer to the impacts resulting from the direct production processes of an industry, while indirect environmental impacts describe the impacts resulting from the use of inputs along the upstream supply chain to produce an industry (Yu et al., 2010).

Settanni et al. (2011) have also highlighted the role of life cycle costing based on an input-output model, which integrates both physical accounting and cost accounting. The input-output framework has been widely applied in various applications, including modeling global material flows (Wiedmann et al., 2013), supply chain analysis (Koh et al., 2013), ecological footprint (Barrett and Scott, 2003), and supply chain benchmarking (Acquaye et al., 2014). Hybridized versions of the input-output framework have been applied at the product level (Treloar, 1997; Suh, 2004) and have formed the basis for carbon accounting systems (Aichele and Felbermayr, 2012), ecological accounting systems (Ewing et al., 2012), and water footprint accounting systems (Feng et al., 2012)

Environmental assessment studies can be conducted in two contrasting approaches that are often considered: a production-based perspective and a consumption-based perspective (Barrett et al., 2013; Schaffartzik et al., 2014). The production-based perspective focuses solely on the direct impacts of industry, neglecting the upstream suppliers' contributions (Peters, 2008; Boitier, 2012). This approach assesses the environmental impacts caused directly by an industry's activities or production processes. However, this paper argues for the development of performance measures from a consumption-based perspective, which takes a systems view and considers emissions attributed to all upstream activities, including imports (Peters, 2008; Boitier, 2012). The consumption-based perspective provides a comprehensive representation of the entire global supply chain network, extending the system boundary to include upstream activities and associated impacts along the supply chain, in addition to the direct impacts. By adopting this perspective, green supply chain management can achieve its key principle of complete supply chain representation (Carter and Easton, 2011; Acquaye et al., 2014). Larsen and Hertwich (2009) also highlight the usefulness of consumption-based accounting as a complementary indicator in performance measurements, alongside traditional production-based accounting, as it provides a more representative view of all supply chain activities.

Additionally, the consumption-based measurement, when employing multi-regional input-output approaches, offers several advantages. It accounts for emissions embodied in international trade, helping to address emissions leakage, expanding mitigation options, and incorporating policies like the Clean Development Mechanism into National Emissions Inventories. Although the consumption-based approach is more complex than the production-based approach (Peters and Hertwich, 2008), its inclusion of upstream activities and international trade emissions provides a more comprehensive and accurate accounting system. That is why, in this paper, the measurement of the environmental sustainability performance for the utility sector of British Columbia is calculated based on the consumption-based approach.

3. Research Methodology

3.1 General input-output methodology

The research topic of this study focuses on measuring the environmental sustainability performance of the supply chain within British Columbia's utility sector, specifically in terms of carbon, sulfur dioxide, and water footprints. In line with this objective, the chosen methodological approach is the general Input-Output (IO) framework, which provides a foundation for quantifying the flows of resources and transactions within the economy (Correa and Craft, 1999). By employing the IO framework, the study transforms the economic flows of the utility sector's supply chain into physical flows of carbon emissions, sulfur dioxide emissions, and water use. This conversion allows for a comprehensive assessment of the environmental impacts associated with the sector's activities. The assumption underlying the IO framework is that all outputs of the utility sector are produced with the same physical flow intensity (Miller and Blair, 2009). This assumption enables the measurement of the sector's environmental footprints, considering the consumption-based perspective.

The adoption of a consumption-based perspective aligns with the concept of lifecycle thinking, as it considers not only the direct emissions and resource use within the utility sector but also the upstream and downstream processes associated with the production and consumption of goods and services. The study acknowledges the significance of these upstream processes, including the production of intermediate products and services used by the utility sector, as well as the consumption patterns of various final demand groups such as households, government, and exports. Furthermore, the research draws on the insights of Wiedmann and Barrett (2011), highlighting that an environmentally extended input-output analysis offers a comprehensive and complete approach to assessing the environmental performance of an industry or sector. This approach eliminates the need for arbitrary system boundaries or truncations, providing a more holistic understanding of the environmental impacts throughout the entire supply chain. In the context of this study, the input-output framework enables the calculation of consumption-based emissions within British Columbia's utility sector by integrating domestic emissions through an input-output (IO) framework, which considers provincial trade transactions (Feng et al., 2014b; Minx et al., 2009; Peters et al., 2011; Scott and Barrett, 2015). By employing the IO framework and adopting a consumption-based perspective, this study aims to measure the carbon, sulfur dioxide, and water footprints of British Columbia's utility sector, thereby providing valuable insights into the environmental sustainability performance of its supply chain.

3.2 Analytical Input-Output Model

The provincial Input-Output (IO) model employed in this study utilizes the Leontief inverse matrix as its foundation. This matrix serves as a basis for generating results that can be used to assess the environmental performance of industrial supply chains using various indicators. The model implemented in this research follows a consumption-based approach to environmental assessment, as supported by previous studies (Barrett et al., 2013; Schaffartzik et al., 2014). In the Input-Output (IO) model, the direct environmental outputs for each industry in the economy are represented by Ej, where Ej corresponds to specific environmental indicators such as carbon emissions, sulfur oxide emissions, and water use. The units of measurement for Ej are 1000 tons of CO2-eq, tons of SOx, and 1000 m3 of water, respectively. To measure the direct intensity environmental impact of a particular industry (j), the total industry production output, represented by xj in constant million dollars, is considered. The direct intensity environmental impact (ed) of industry j is then calculated as the ratio of Ej to xj (equation 1).

$$\mathbf{ed} = \frac{Ej}{Xj} \tag{1}$$

The direct intensity environmental impact (ed) measurement discussed earlier focuses solely on an industry's direct production activities, providing insight into the direct impacts per unit dollar of output. This measurement allows for a comparison of an industry's performance, whether at the company or industry level, with the performance of the entire supply chain. These direct-intensity environmental impacts (ed) for all industries are presented in the model as a row matrix (ed) (Acquaye, A. et al., 2016).

In this research, the IO (Input-Output) model serves as a comprehensive framework to assess the environmental impacts of industrial supply chains. Unlike the limited production-based approach in Equation (1) used for industrial-level performance measurement, the IO model employs a consumption-based approach, capturing both direct and indirect activities of industries. Equation (2) expresses the IO model, where the impacts are equal to the product of the direct intensity environmental impacts (ed) and the Leontief inverse matrix (L)

$$\textbf{Impact} = \textbf{ed.L} = \textbf{ed.(I-A)}^{-1} = \textbf{ed.(A0+A1+A2+A3+....)} \qquad (2)$$

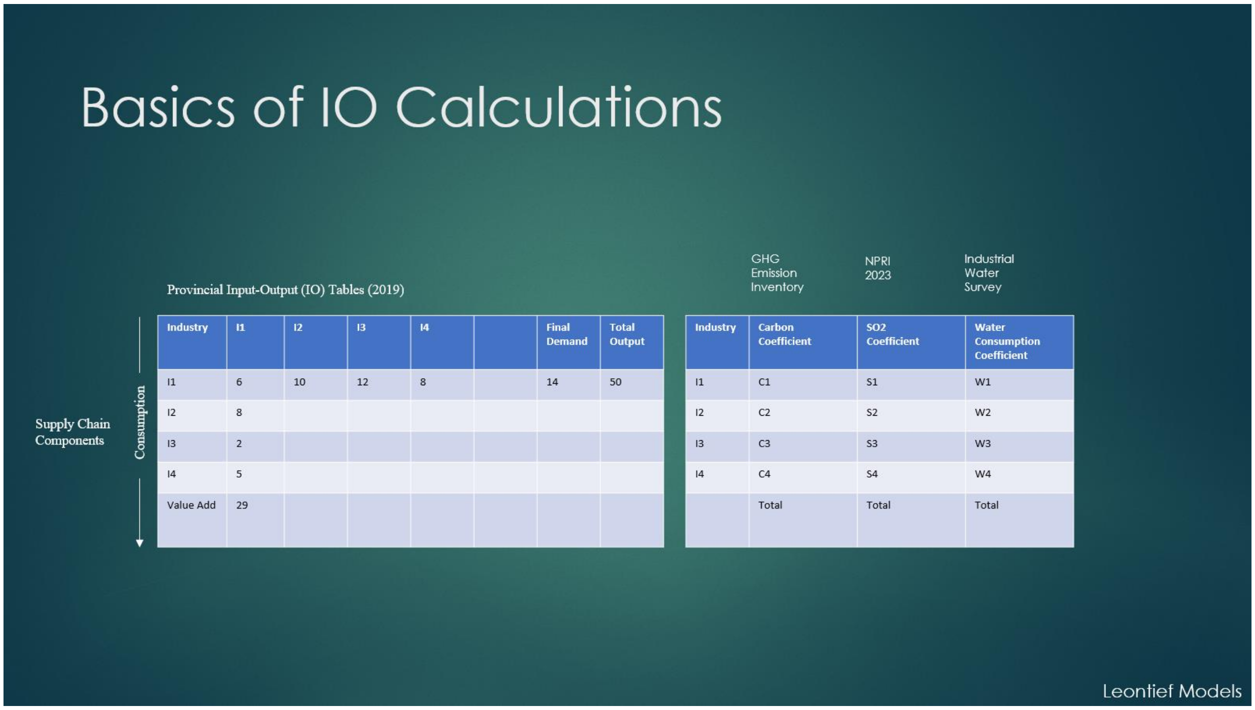
To be more specific, the IO model is defined in Equation (3) using the structure adopted in this paper. It consists of the Leontief inverse matrix (L) and the input-output matrix (A), with which I represent the identity matrix. This formulation allows for a comprehensive assessment of the environmental impacts throughout the entire supply chain, considering the interdependencies between industries and capturing the effects of imported goods and services used either indirectly or directly as inputs.

$$\textbf{Impact} = \textbf{ed.L} = \textbf{ed.(}\begin{bmatrix} \mathbf{1} & \cdots & \mathbf{0} \\ \vdots & \ddots & \vdots \\ \mathbf{0} & \cdots & \mathbf{1} \end{bmatrix} - \begin{bmatrix} \boldsymbol{A11} & \cdots & \boldsymbol{A1n} \\ \vdots & \ddots & \vdots \\ \boldsymbol{An1} & \cdots & \boldsymbol{Ann} \end{bmatrix}\textbf{)}^{-1} \qquad (3)$$

By employing a consumption-based perspective, the IO model overcomes the limitations of a production-based approach, which only considers impacts within an organization's fixed boundaries and neglects the effects of multiple supply chain factors. This broader perspective enables a complete representation of the supply chain, capturing the environmental impacts associated with transactions of goods and services used along supply chains. Consequently, it aligns with the principle of green supply chain management (Zhu et al., 2008), which emphasizes the need for a comprehensive representation of the entire supply chain.

Figure 2

Basics of IO Calculations



Note. Basics of IO Calculations. The above figure shows the basic mechanism used for the calculation of the IO tables during the research.

3.3 Data Sources

The provincial Input-Output (IO) Model was created using the provincial Input-Output tables and Environmental data from the government of Canada and British Columbia. The provincial Input-Output (IO) Tables (2019) were received from Statistics Canada (Statistics Canada, 2022), which contain direct and indirect spending across the supply chain of economic sectors in Canada. For the creation of Environmental Input-Output tables for BC, the detailed level data from the provincial tables are used as it provides granularity for the industries considered in the evaluation of the supply chain of the Utility Sector of BC.

The GHG Gas Emission data were used to calculate Carbon Footprints, published by the Government of British Columbia (Government of BC, 2020). The data contains GHG gas emissions across the economic sectors of British Columbia and has a granularity level till the component of GHG gases. This helped in estimating the carbon emission per economic sector, which was used to evaluate the carbon footprints of supply chain components of the utility sector of BC. The Government of Canada also publishes National Pollutant Release Inventory data annually on its website (NPRI, 2023). For calculating the Sulphur Dioxide footprints of the Utility Sector of BC, the Bulk data files for all years published by the Government of Canada were used (NPRI Release, 2020). The NPRI Release data was useful to get the Sulphur Dioxide Emission from 2002 to 2020 across the economic sectors. This data for the emission of Sulphur Dioxide in tonnes per economic sector was further integrated with the provincial input-output tables to evaluate the Sulphur Dioxide footprints for the supply chain components of the utility sector of BC. Finally, for evaluating water footprints across the utility sector of BC, the Industrial Water Survey published by the Government of Canada was used (IWS, 2020). The data for the industrial water survey is not published in line with the economic sectors of Canada, which is observed as one of the limitations for calculating the water footprint of the Utility Sector of BC using Environmental Input-Output tables calculated for this research.

Input-Output analysis provides a base for the measurement of Sustainability Performance of the Supply Chain. The analysis conducted during the research project also suggests that the Input-Output Analysis tables are helpful in getting a comprehensive and directive overview of Supply Chain's Health and establish Inter-Industry linkages. Data Sources provided by Government of Canada and Government of British Columbia compliments the calculation of Carbon Footprints and SO2 Footprints using Input-Output Method. Data Sources provided by Government of Canada (IWS, 2022) doesn't compliment the calculation for Water Footprint using Input-Output Method.

3.4 Software Tools

The analysis was conducted using a combination of Tableau Public and Microsoft Excel, which are widely recognized and utilized tools in the field of data analysis and visualization. The data utilized in this analysis was obtained from credible sources, namely the Government of Canada and the Government of British Columbia. Microsoft Excel was employed to perform essential calculations for various aspects of the analysis, including the computation of IO (Input-Output) analysis for Carbon Footprint, Sulphur Dioxide Footprint, and Water Footprint. Excel's robust computational capabilities and flexibility were leveraged to ensure precise calculations and effective data manipulation.

Following the processing and refinement of the data in Excel, it was seamlessly transferred to the public version of Tableau for data visualization. Tableau is renowned for its intuitive interface and advanced visualization features, making it an ideal choice for presenting complex data visually appealing and easily comprehensibly. All the charts used in this analysis are adopted from Tableau Public. The combination of Excel's analytical capabilities and Tableau's visualization prowess ensured a comprehensive and professional data analysis.

3.5 Descriptive Analysis for Selected Data Sources

3.5.1 Carbon Emission (provincial_inventory_of_greenhouse_gas_emissions 1990-2020)

- Datasets: Activity Categories, Economic Sectors, Gases
- Gases: Carbon Dioxide (Co2), Methane (Ch4), Nitrous Oxide (N2o), Hydrofluorocarbons (Hfcs), Perfluorocarbons (Pfcs), Sulphur Hexafluoride (Sf6), Nitrogen Trifluoride (Nf3).
- Total GHG Emission = 1974.6 MtCO2e (1990-2020)
- Average GHG Emission = 63.7 MtCO2e (1990-2020)
- Variables 2: GHG Emission in MtCO2e and Year (Timeseries Data)

3.5.2 Sulphur Emission (NPRI Releases1993-2021)

- Dataset Variables: 17
- Variables used for Research: 4

- Names of Variable Used: Reporting Year, Province, Substance Name, Quantity
- Province: BC
- Year Used for IO: 2019
- Substance Name: Sulphur Dioxide
- Total Release: 948525.3018 tonnes (1993-2021)
- Avg: 345.9246 tonnes (1993-2021)

3.6.3 Industrial Water Intake

- Dataset Variables: 15
- Variables used for Research: 4
- Names of Variable Used: REF Date, GEO, Value, UOM, SCALAR FACTOR
- REF Date: 2005-2020
- GEO: British Columbia
- UOM: Cubic meters
- SCALAR FACTOR: millions
- Total Used: 11949 million cubic meters
- Avg: 248.93 million cubic meters

3.7 Scope and Limitations

3.7.1 Scope

The research study focused on measuring the environmental sustainability performance of the supply chain in British Columbia's (BC) utility sector. Industries examined included electricity generation, transmission, and distribution; natural gas extraction, processing, and distribution; oil and gas transmission; and petroleum refineries (Government of BC, 2020). The study utilized reliable government data sources from the Government of Canada and the Government of BC, covering 2002 to 2020. To assess sustainability performance, the study created the provincial Input-Output (IO) Model, which incorporated provincial Input-Output tables and environmental data (Statistics Canada, 2022) for the year 2019. This approach allowed for a comprehensive evaluation of direct and indirect spending patterns across the supply chain, enabling insights into the sector's sustainability performance.

Carbon footprints were calculated using GHG emission data from 1990 to 2020 published by the Government of BC (Government of BC, 2020). Sulfur dioxide footprints were estimated using the National Pollutant Release Inventory (NPRI) data from 2002 to 2020 (NPRI Release, 2020). Water footprints were assessed using data from the Industrial Water Survey published by the Government of Canada (IWS, 2020). It is important to acknowledge the study's limitations, including potential inaccuracies associated with government data sources and the narrow focus on BC's utility sector. Therefore, generalizing the findings to other sectors or regions should be done with caution. However, the research provides valuable insights into the environmental sustainability performance of the identified industries within the specified time frame.

3.7.2 Limitations

3.7.2.1 Data Limitations: The study relies on data obtained from government sources such as the Government of Canada and the Government of British Columbia (BC). While these sources are generally credible, it is important to consider potential limitations in data accuracy, completeness, and timeliness (Correa & Craft, 1999; Statistics Canada, 2022). The data may not capture the full range of environmental impacts or may have gaps and uncertainties, particularly regarding water footprints where the available data does not align with the economic sectors considered in the study (IWS, 2020).

3.7.2.2 Generalizability: The study focuses specifically on measuring the environmental sustainability performance of the supply chain within BC's utility sector. Therefore, the findings may not be directly applicable to other sectors or regions, as different sectors can have unique supply chain characteristics and environmental impacts (Wiedmann & Barrett, 2011). Additionally, the assumption that all outputs of the utility sector have the same physical flow intensity may oversimplify the complexity of the sector and introduce inaccuracies (Miller & Blair, 2009).

3.7.2.3 Simplifying Assumptions: The study relies on the input-output (IO) framework, which makes simplifying assumptions such as fixed technical coefficients and linear relationships between industries (Acquaye et al., 2016). These assumptions may not fully capture the dynamic and nonlinear nature of supply chains and could potentially underestimate or oversimplify the environmental impacts.

3.7.2.4 Incomplete Consideration of Indirect Effects: While the IO framework employed in the study accounts for indirect activities and interdependencies within the supply chain, it may not fully capture all indirect effects and external factors that influence environmental sustainability performance. Factors such as changes in consumer behavior, technological advancements, policy interventions, and global market dynamics could significantly impact the results but are not comprehensively addressed (Schaffartzik et al., 2014).

3.7.2.4 Lack of Qualitative Analysis: The study primarily focuses on quantitative analysis by quantifying the carbon, sulfur dioxide, and water footprints of the utility sector's supply chain. It does not extensively address qualitative aspects, such as social or economic impacts, which are important considerations for a comprehensive sustainability assessment (Barrett et al., 2013). Incorporating qualitative analysis would provide a more holistic understanding of environmental sustainability performance.

3.7.2.5 Limited Future Projections: The study utilizes data from a specific time and does not consider future projections or scenarios. This limits the ability to assess long-term sustainability implications and anticipate the effects of potential policy interventions or technological advancements (Minx et al., 2009). The dynamic nature of environmental performance and changing external factors should be considered for a more robust analysis.

3.7.2.6 Model Limitations: The analytical input-output model used in the study, while providing a comprehensive framework, has inherent limitations. These include the assumption of linear relationships and the challenge of capturing all inter-industry linkages and multi-regional trade dynamics. These limitations can affect the accuracy and reliability of the results (Feng et al., 2014b; Peters et al., 2011).

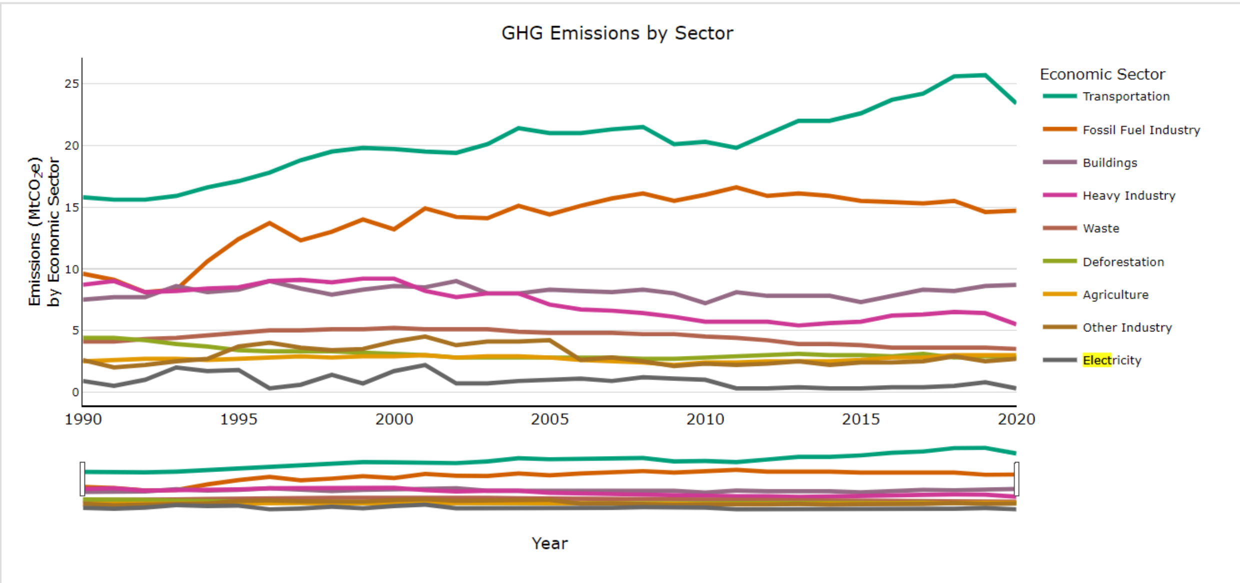
It is crucial to critically consider these limitations when interpreting the findings of the study. Further research is necessary to address these limitations and refine the methodology to improve the accuracy of environmental sustainability assessments in the supply chain of BC's utility sector. Additionally, incorporating qualitative analysis and considering future projections would provide a more comprehensive and robust understanding of the sector's environmental performance.

4. Result and Discussion

4.1 Carbon Footprints for Utility Sector's in British Columbia

Figure 3

GHG emission in British Columbia by Sector



Note. The graph is published by British Columbia Government in 2023, showing a comparison of GHS emissions in British Columbia by Sector. From "Trends in Greenhouse Gas Emissions in BC (1990-2020)" by Environmental Reporting, British Columbia, January 2023. https://www.env.gov.bc.ca/soe/indicators/sustainability/ghg-emissions.html

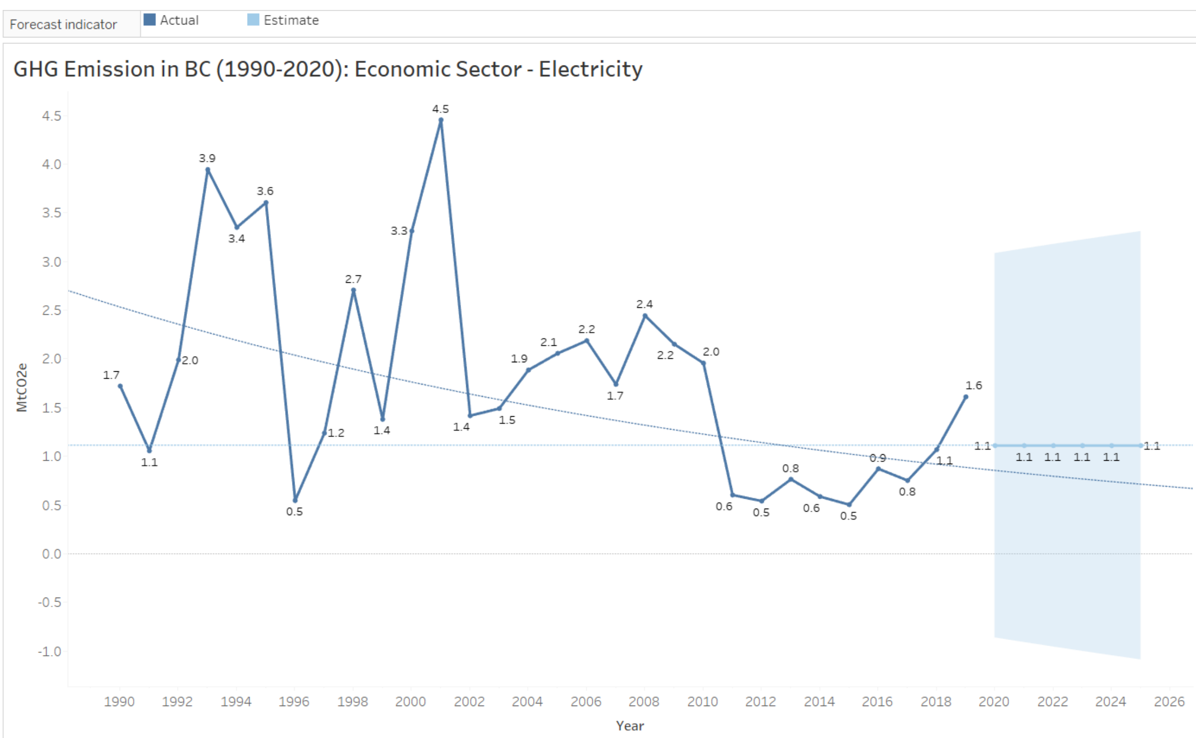
The analysis of GHG emissions by economic sector for BC revealed that the transportation sector in BC has the maximum GHG gas emission, and the electricity sector has had the least GHG emission since 1990. The British Columbia (BC) province has established ambitious targets for reducing greenhouse gas (GHG) emissions within the next three decades. These targets aim to achieve a 40% reduction from 2007 levels by 2030, a 60% reduction by 2040, and an 80% reduction by 2050. BC Government has set interim targets to ensure that BC remains on course to meet these goals, requiring a 16% reduction in GHG emissions from 2007 levels by 2025 (BC Government, 2022). Let's understand the findings of this analysis related to carbon footprints in the supply chain of the utility sector of BC in the following section.

4.1.1 GHG Gas Emission

4.1.1.1 Electricity: The analysis of provincial greenhouse gas emissions inventory data shows that the GHG gas emission in the Electricity sector has lowered in past years and is below the overall GHG emissions from the other sectors.

Figure 4

GHG Emission in BC (1990-2020) for the Economic Sector – Electricity



Note. GHG Emission in BC (1990-2020) for the Economic Sector – Electricity. The data was adapted from Tableau Public Dashboard created for this analysis. https://public.tableau.com/

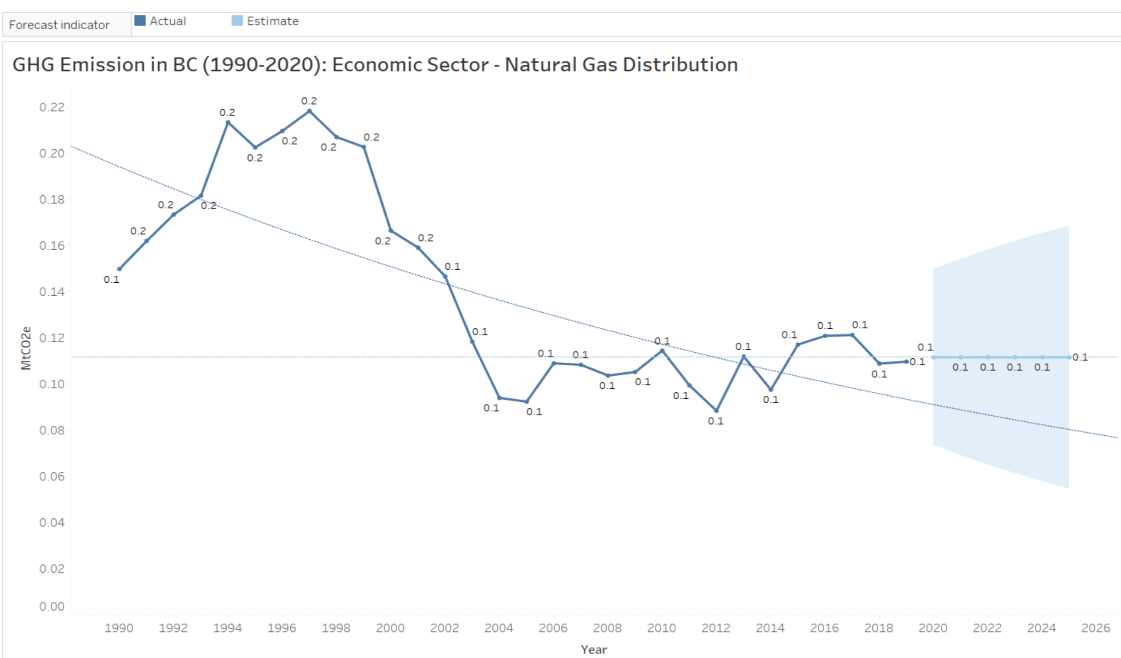
views/MtCO2-BCCanada/Dashboard1GHGEmission?:language=en-US&publish=yes&:display_count=n&:origin=viz_share_link

4.1.1.2 Natural Gas

Figure 4 shows that the economic sector, Natural Gas Distribution, has significantly decreased GHG emissions. This is the result of Canada's commitment to reduce GHG emissions from Natural gas production and distribution through adopting new technologies and targeted reduction in Methane emissions (Canada's Oil and Natural Gas Producers, 2021). Canada has mandated a reduction in methane emissions of 45% below 2012 levels by 2025, making them a unique country among the world's top 10 petroleum exporters with a methane reduction target (Canada's Oil and Natural Gas Producers, 2021).

Figure 5

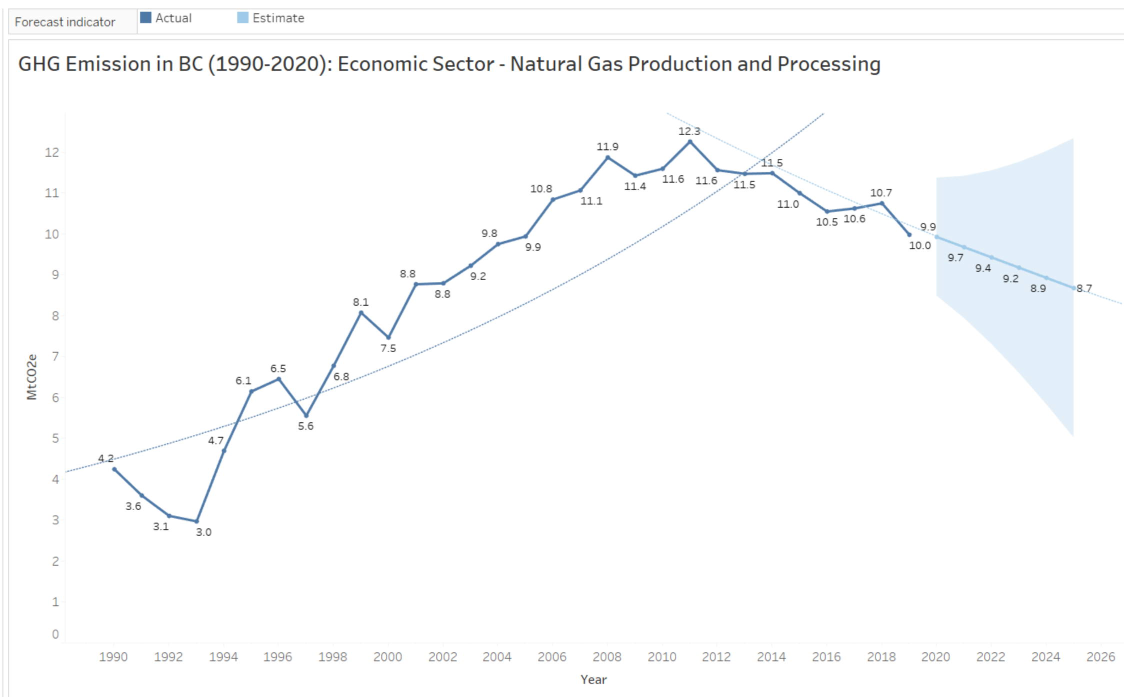
GHG Emission in BC (1990-2020) for the Economic Sector – Natural Gas Distribution



Note. GHG Emission in BC (1990-2020) for the Economic Sector – Natural Gas Distribution. The data was adapted from Tableau Public Dashboard created for this analysis. https://public.tableau.com/views/MtCO2-BCCanada/Dashboard1GHGEmission?:language=en-US&publish=yes&:display_count=n&:origin=viz_share_link

Figure 6

GHG Emission in BC (1990-2020) for the Economic Sector – Natural Gas Production and Processing



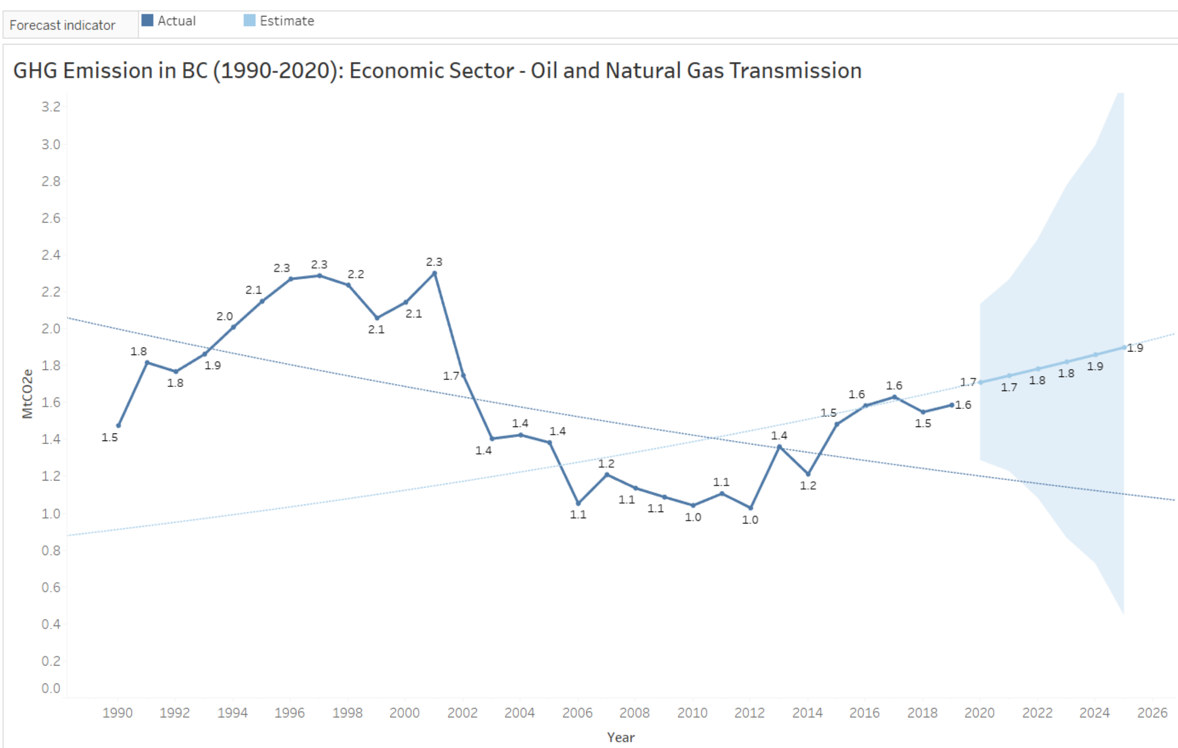
Note. GHG Emission in BC (1990-2020) for the Economic Sector – Natural Gas Production and Processing. The data was adapted from Tableau Public Dashboard created for this analysis. https://public.tableau.com/views/MtCO2-BCCanada/Dashboard1GHGEmission?:language=en-US&publish=yes&:display_count=n&:origin=viz_share_link

4.1.1.3 Oil and Natural Gas Transmission

The GHG emission in the oil and natural gas sector has reduced over time. From the level of 1.8 MtCO2e in 1990, it went high to 2.3 MtCO2e from 1996 to 2001. The rise signifies the increase in demand for oil and natural gas during this period. In 2010, the emission was reported as low as 1.0 MtCO2e, which is the lowest across the selected time frame for analysis. The lower emission of GHG gases during this period is the result of British Columbia's Oil and Gas Activities Act which was introduced to regulate oil and gas and related activities in BC, including wells, facilities, oil refineries, natural gas processing plants, pipelines, and oil and gas roads, through permits, authorizations, orders, and regulations (BC Government, n.d.).

Figure 7

GHG Emission in BC (1990-2020) for the Economic Sector – Oil and Natural Gas Transmission



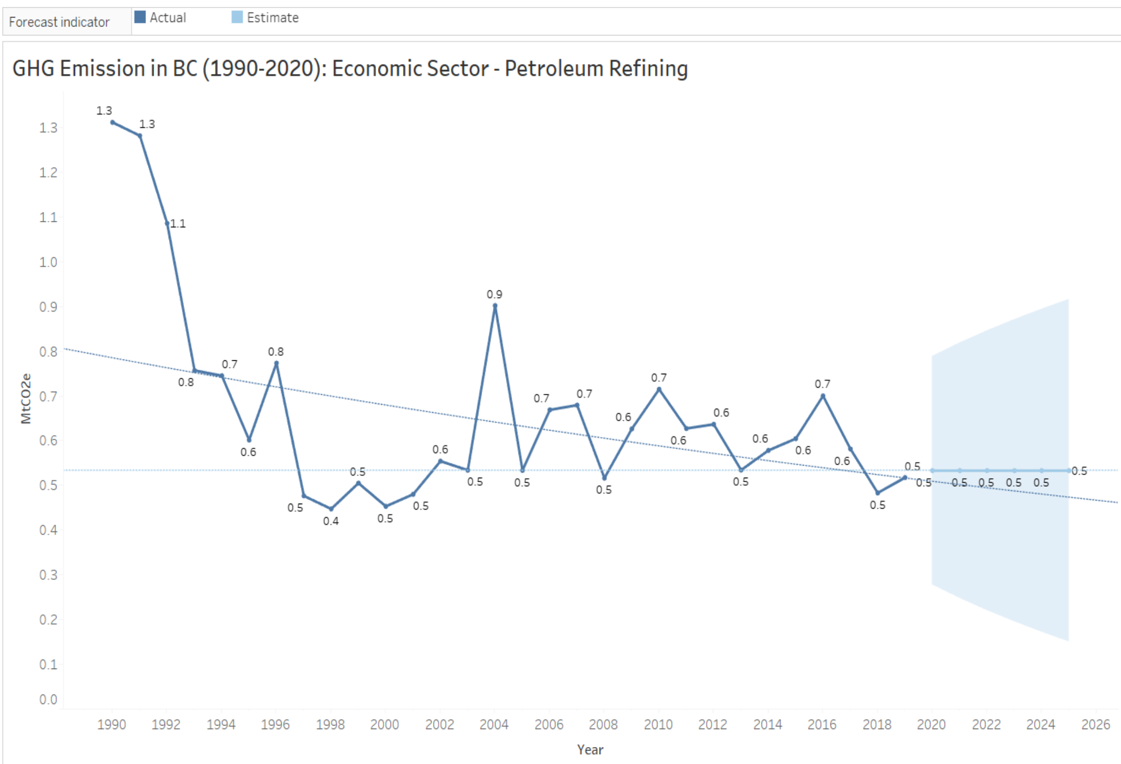
Note. GHG Emission in BC (1990-2020) for the Economic Sector – Oil and Natural Gas Transmission. The data was adapted from Tableau Public Dashboard created for this analysis.

https://public.tableau.com/views/MtCO2-BCCanada/Dashboard1GHGEmission?:language=en-US&publish=yes&:display_count=n&:origin=viz_share_link

4.1.1.4 Petroleum Refining

Figure 8

GHG Emission in BC (1990-2020) for the Economic Sector – Petroleum Refining



Note. GHG Emission in BC (1990-2020) for the Economic Sector – Petroleum Refining. The data was adapted from Tableau Public Dashboard created for this analysis.

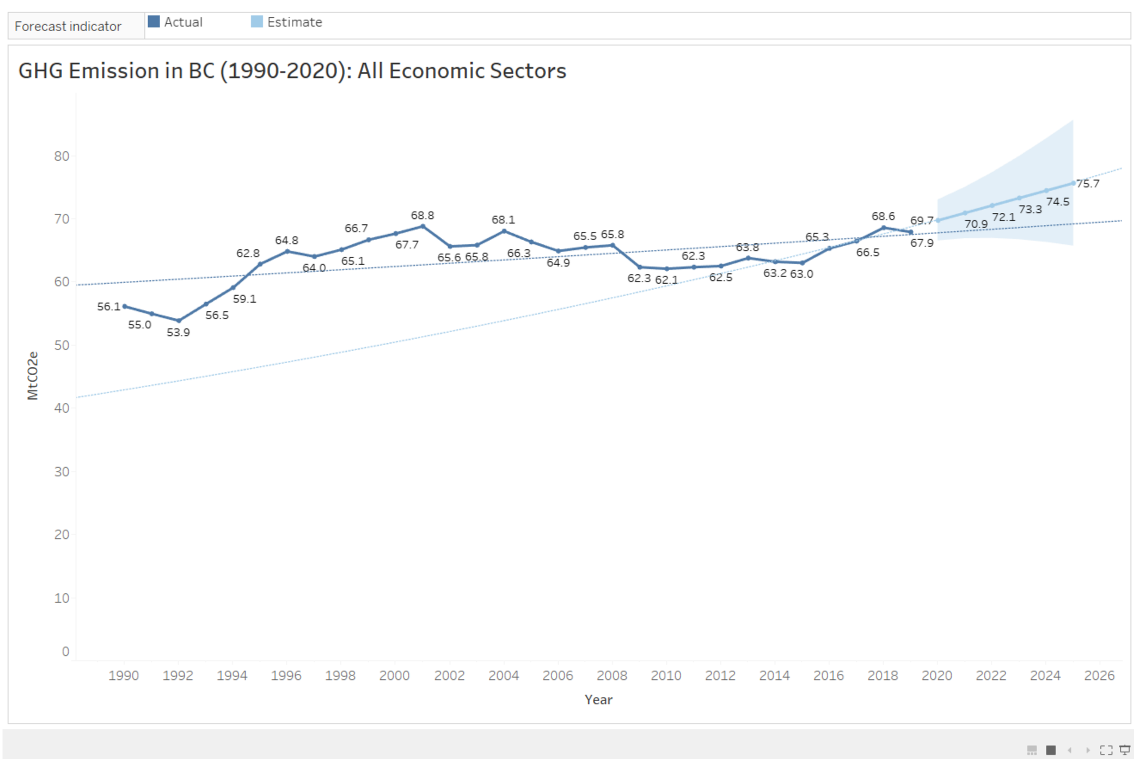
https://public.tableau.com/views/MtCO2-BCCanada/Dashboard1GHGEmission?:language=en-US&publish=yes&:display_count=n&:origin=viz_share_link

4.1.1.5 Comparison with Other Sectors

In the year 2020, the gross greenhouse gas (GHG) emissions in British Columbia (BC), as reported in the Provincial Inventory, amounted to 64.6 million tonnes of carbon dioxide equivalent (MtCO2e). This figure indicates a reduction of 0.9 MtCO2e (-1%) compared to the baseline year of 2007, during which the emissions were recorded at 65.5 MtCO2e (Government of BC, 2020). The analysis shows that the overall MtCO2e emissions of BC have been stable since 2008. However, the tableau forecasting shows a slight increase in the coming years. The comparison of the Utility sector and other sectors shown in the below figure indicates that the Utility Sector of BC has considerably lower MtCO2 emissions as compared to the other sectors. In 2020, the overall emission was 64.6 tonnes of MtCO2e, out of which 13.3 tonnes were from the Utility Sector.

Figure 9

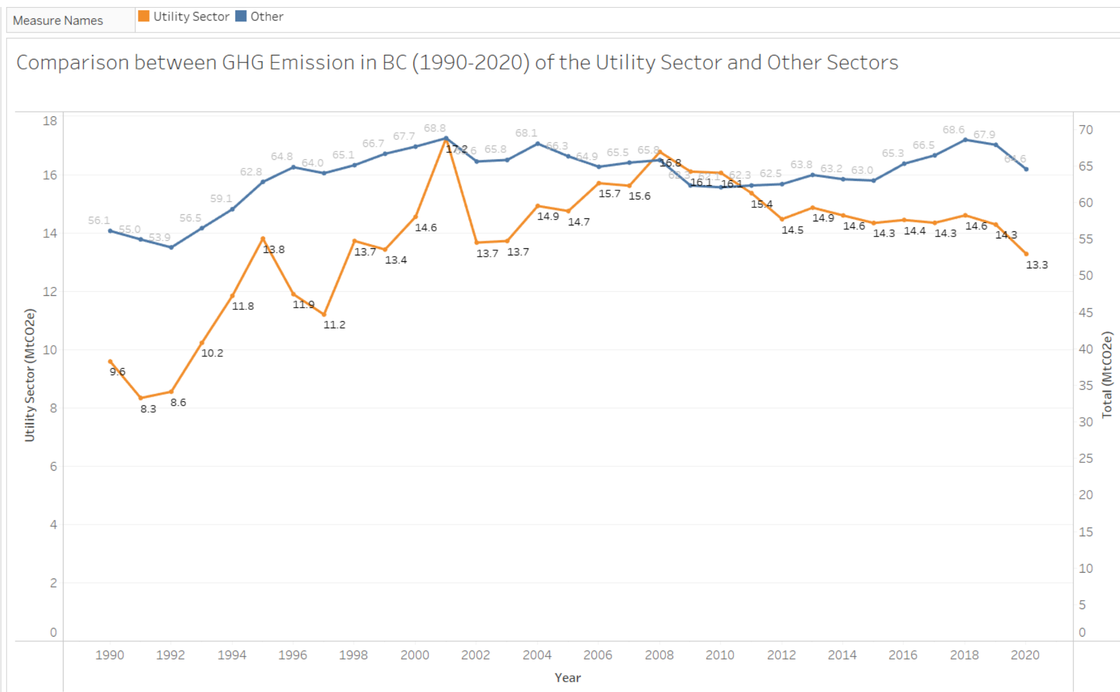
GHG Emission in BC (1990-2020): All Economic Sector



Note. GHG Emission in BC (1990-2020) for the Economic Sector – All Economic Sectors. The data was adapted from Tableau Public Dashboard created for this analysis. https://public.tableau.com/views/MtCO2-BCCanada/Dashboard1GHGEmission?:language=en-US&publish=yes&:display_count=n&:origin=viz_share_link

Figure 10

Comparison of the Utility Sector and Other Sectors for the GHG Emission in BC (1990-2020)



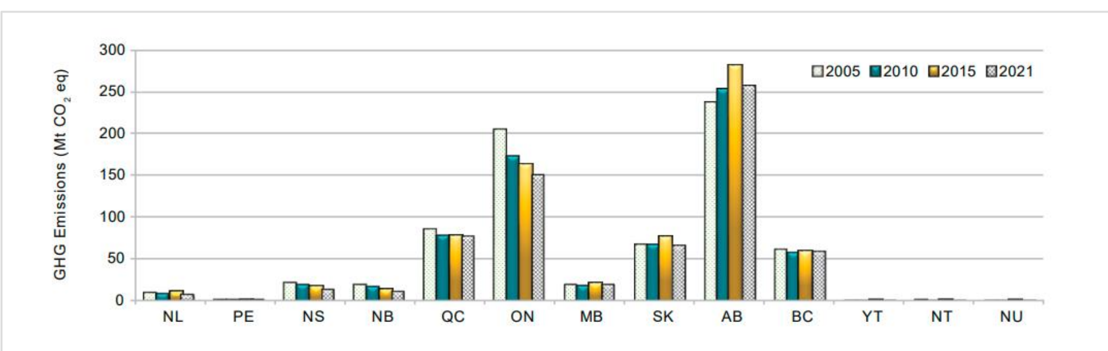
Note. GHG Emission in BC (1990-2020) of the Utility Sector and Other Sectors. The data was adapted from Tableau Public Dashboard created for this analysis. https://public.tableau.com/views/MtCO2-BCCanada/Dashboard3?:language=en-US&publish=yes&:display_count=n&:origin=viz_share_link

4.1.1.6 Comparison with Other Provinces

The below figure shows the comparison between the MtCO2 emissions of BC and other Provinces in Canada. When comparing these emission trends with British Columbia (BC), it is important to note that BC has achieved a decrease in emissions of 2.2 Mt (3.6%) from 2005 to 2021. This indicates that BC has made progress in reducing its GHG emissions, albeit to a lesser extent compared to some other provinces (GREENHOUSE GAS SOURCES AND SINKS IN CANADA, 2021). The specific factors influencing BC's emission levels would require further analysis and consideration. During the period between 2005 and 2021, most sub-national jurisdictions across Canada have observed a decline in emissions. Notably, Nova Scotia has achieved a reduction of 8.2 Mt (36%), Quebec has seen a decrease of 8.1 Mt (9.4%), New Brunswick has experienced a decline of 7.7 Mt (39%), British Columbia has recorded a decrease of 2.2 Mt (3.6%), Newfoundland and Labrador have witnessed a reduction of 1.9 Mt (18%), Saskatchewan has achieved a decrease of 0.7 Mt (1.0%), the Northwest Territories has experienced a decline of 0.44 Mt (25%), and Prince Edward Island has recorded a reduction of 0.25 Mt (13%); however, emissions have increased in Manitoba by 0.40 Mt (2.0%), Yukon by 0.09 Mt (16%), and Nunavut by 0.04 Mt (7.2%) (GREENHOUSE GAS SOURCES AND SINKS IN CANADA, 2021).

Figure 11

GHG Emission by Province and Territory in 2005, 2010, 2015, and 2021



Note. GHG Emission by Province and Territory in 2005, 2010, 2015, and 2021. Adapted from NATIONAL INVENTORY REPORT 1990 –2021: GREENHOUSE GAS SOURCES AND

SINKS IN CANADA (2021). Retrieved on 1 June 2023.

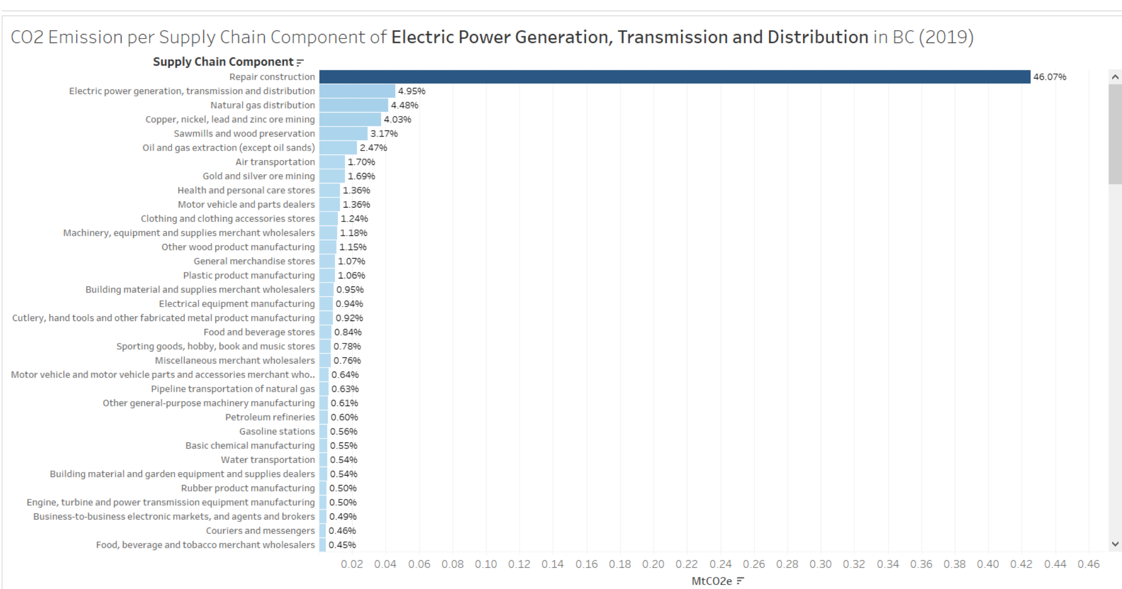
https://publications.gc.ca/collections/collection_2023/eccc/En81-4-2021-1-eng.pdf

4.1.2 CO2 Emissions

With the help of IO Tables and provincial greenhouse gas inventory data for CO2 emission per economic sector, the CO2 emission component of the Supply Chain of the Electricity Sector was calculated. The calculations found that for 2019, the total CO2 emission was 0.805 MtCO2e. Out of which, the Repair of Construction, Electricity Power Generation and Transmission, Natural Gas Distribution, Copper, Nickel, Lead, Zinc Ore Mining, Sawmills, and Wood Preservations are the top 5 components for the CO2 emission of the Supply Chain of the Electricity Sector of British Columbia.

Figure 12

CO2 Emission per Supply Chain Components related to Electricity Industry in BC



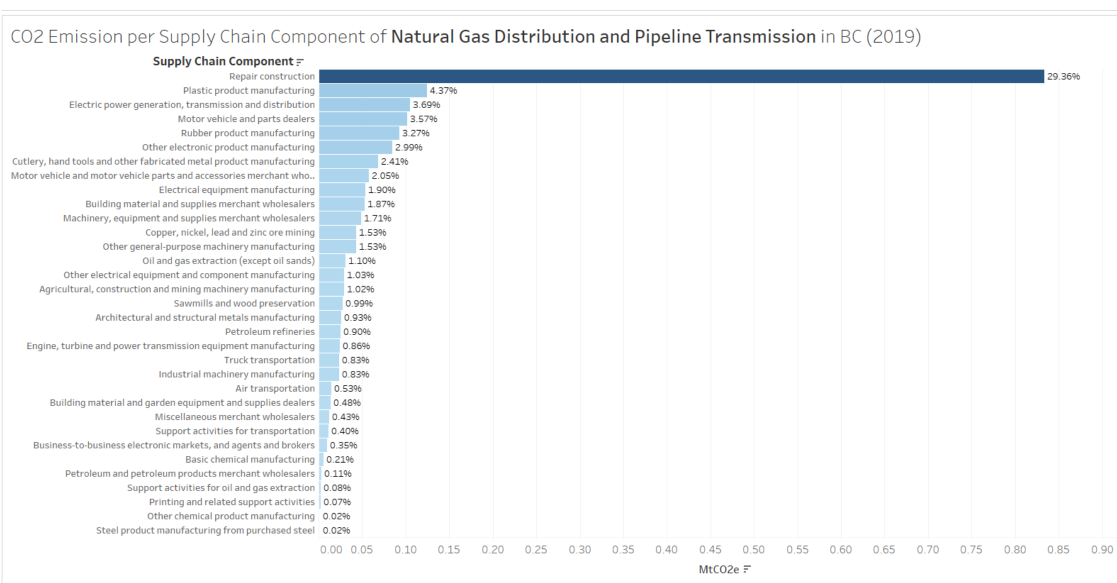
Note. CO2 Emission per Supply Chain Components related to Electricity Industry in BC. The data was adapted from Tableau Public Dashboard created for this analysis.

https://public.tableau.com/views/CO2EmissionperSupplyChainComponentBC2019/Dashboard2CO2Footprints?:language=en-US&publish=yes&:display_count=n&:origin=viz_share_link

The carbon footprints for the Natural Gas Distribution and Pipeline Transmission were also calculated based on the IO tables and provincial greenhouse gas inventory. It was found that for the year 2019, the total CO2 emission for this sector was 2.84 MtCO2e. The components like Repairing Construction, Plastic Product Manufacturing, Electricity Power Generation, Transmission and Distribution, Motor Vehicle and Parts Dealers, and Rubber Product Manufacturing are the top contributor to the Supply Chain of the Natural Gas Distribution and Pipeline Transmission industry.

Figure 13

CO2 Emission per Supply Chain Components related to Natural Gas Distribution and Pipeline Transmission Industry in BC

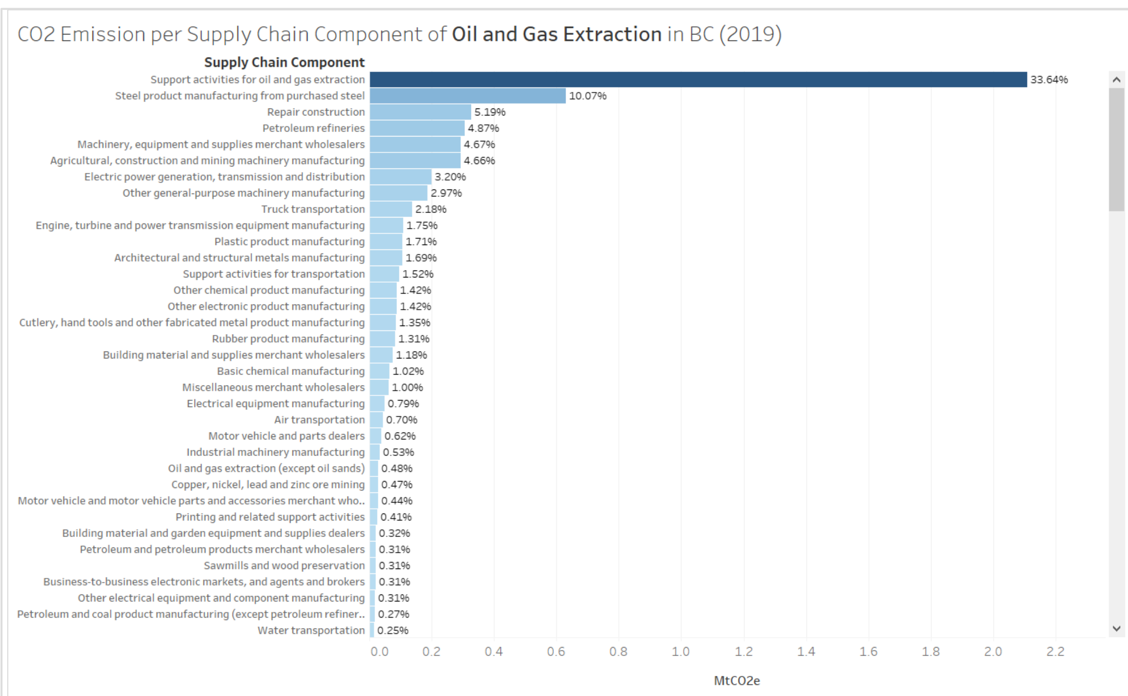


Note. CO2 Emission per Supply Chain Components related to Natural Gas Distribution and Pipeline Transmission Industry in BC. The data was adapted from Tableau Public Dashboard created for this analysis. https://public.tableau.com/views/CO2EmissionperSupplyChainComponentBC2019/Dashboard2CO2Footprints?:language=en-US&publish=yes&:display_count=n&:origin=viz_share_link

The research also evaluated the Oil and Gas Extraction Industry as a part of the Utility Sector of BC. The total CO2 emission for 2019 for this sector was 6.27 MtCO2e. This is the highest contributor to CO2 emission in the analyzed industries of the Utility Sector of BC. The top five supply chain component for the CO2 emission of this sector are Supporting Activities for Oil and Gas Extraction, Steel Product Manufacturing from the Purchased Steel, Repair Construction Works, Petroleum Refineries and Machinery, Equipment, and Supplies Merchants.

Figure 14

CO2 Emission per Supply Chain Components related to Oil and Gas Extraction Industry in BC



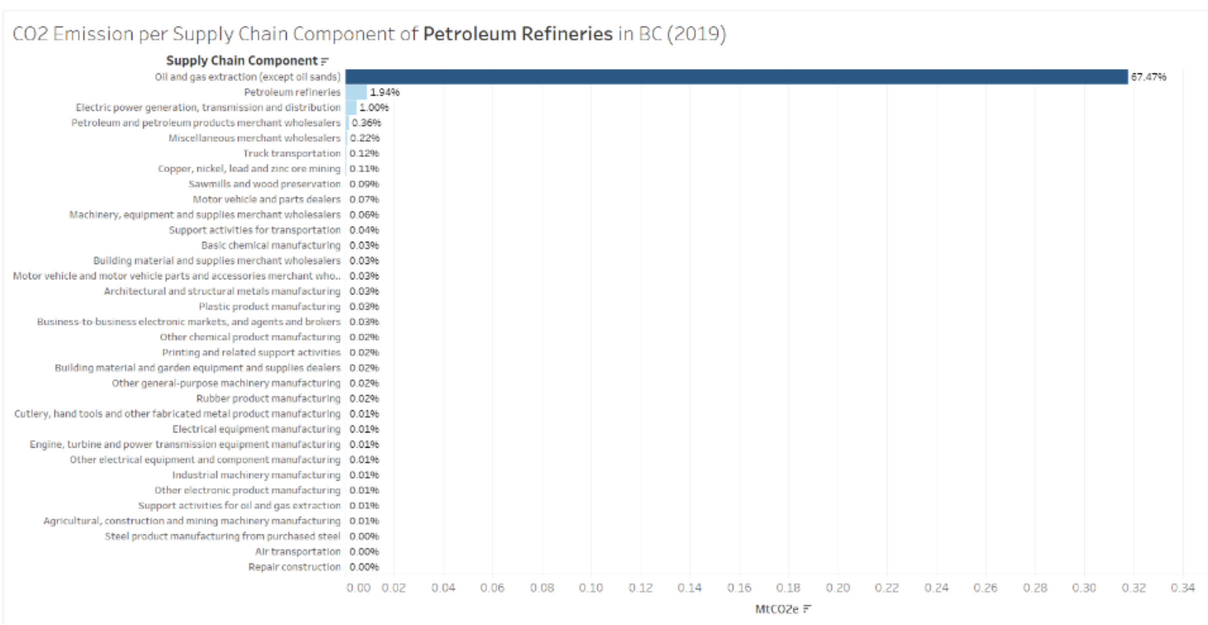
Note. CO2 Emission per Supply Chain Components related to Oil and Gas Extraction Industry in BC. The data was adapted from Tableau Public Dashboard created for this analysis.

https://public.tableau.com/views/CO2EmissionperSupplyChainComponentBC2019/Dashboard2CO2Footprints?:language=en-US&publish=yes&:display_count=n&:origin=viz_share_link

The Petroleum Refineries Industry was also selected as a source of the Utility Sector in BC. The analysis found that the total CO2 emission for the Petroleum Refineries Industry was 0.47 MtCO2e. The analysis shows that, for the year 2019, the top five contributors to the CO2 emission in this industry are Oil and Gas Extraction (except sands), Petroleum Refineries, Electric Power Generation and Transmission, Petroleum, and Petroleum Product Merchant Wholesalers and Miscellaneous Merchant Wholesalers.

Figure 15

CO2 Emission per Supply Chain Components related to Petroleum Refineries Industry in BC



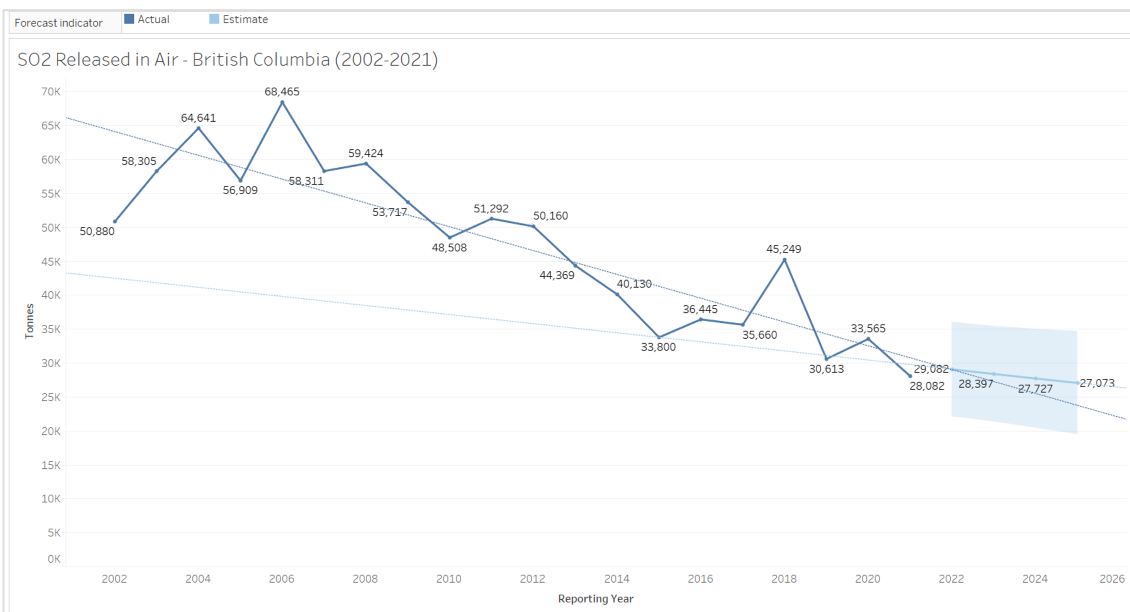
Note. CO2 Emission per Supply Chain Components related to Petroleum Refineries Industry in BC. The data was adapted from Tableau Public Dashboard created for this analysis. https://public.tableau.com/views/CO2EmissionperSupplyChainComponentBC2019/Dashboard2CO2Footprints?:language=en-US&publish=yes&:display_count=n&:origin=viz_share_link

4.2 Sulphur Dioxide Footprints

Using the IO tables (Government of BC, 2020) and NPRI data (NPRI, 2023), the Sulphur Dioxide footprints were evaluated for the industries in the utility sector of British Columbia for 2019. The analysis found that the Oil and gas extraction (except oil sands) and Petroleum Refineries Industry has the maximum Sulphur release for the Utility Sector of BC Below figure shows the overall Sulphur Dioxide emission in BC (2002-2021). The overall SO2 emission in BC is lowering if we look at the levels of 2002. The SO2 emission in Air reduced to 30.61 tonnes in 2019 as compared to 50.88 tonnes in 2002.

Figure 16

SO2 emission in Air – British Columbia (2002-2021)



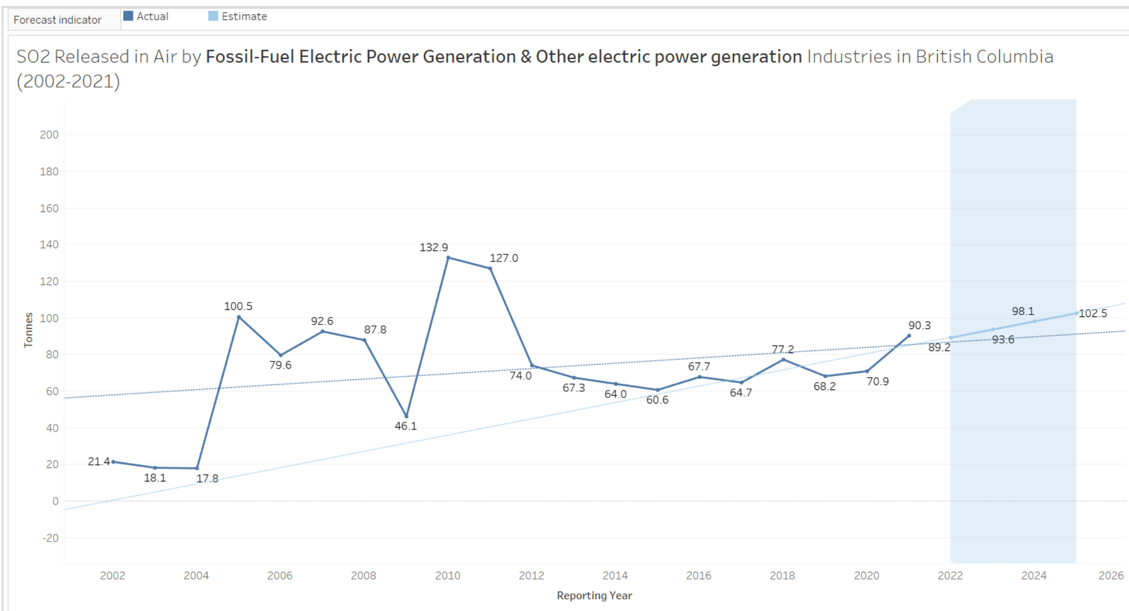
Note. SO2 emission in Air – British Columbia (2002-2021). The data was adapted from Tableau Public Dashboard created for this analysis. https://public.tableau.com/views/SO2Emission-BC/Dashboard5?:language=en-US&publish=yes&:display_count=n&:origin=viz_share_link

4.2.1 Electricity

The electricity sector had a total Sulphur Dioxide release of 68.15 tonnes in 2019, out of which the top 5 supply chain components were Repair Construction, Electric Power Generation, Transmission and Distribution, Natural Gas Distribution, Copper, Nickel, Lead, and Zinc Ore Mining, Sawmills and Wood Preservations.

Figure 17

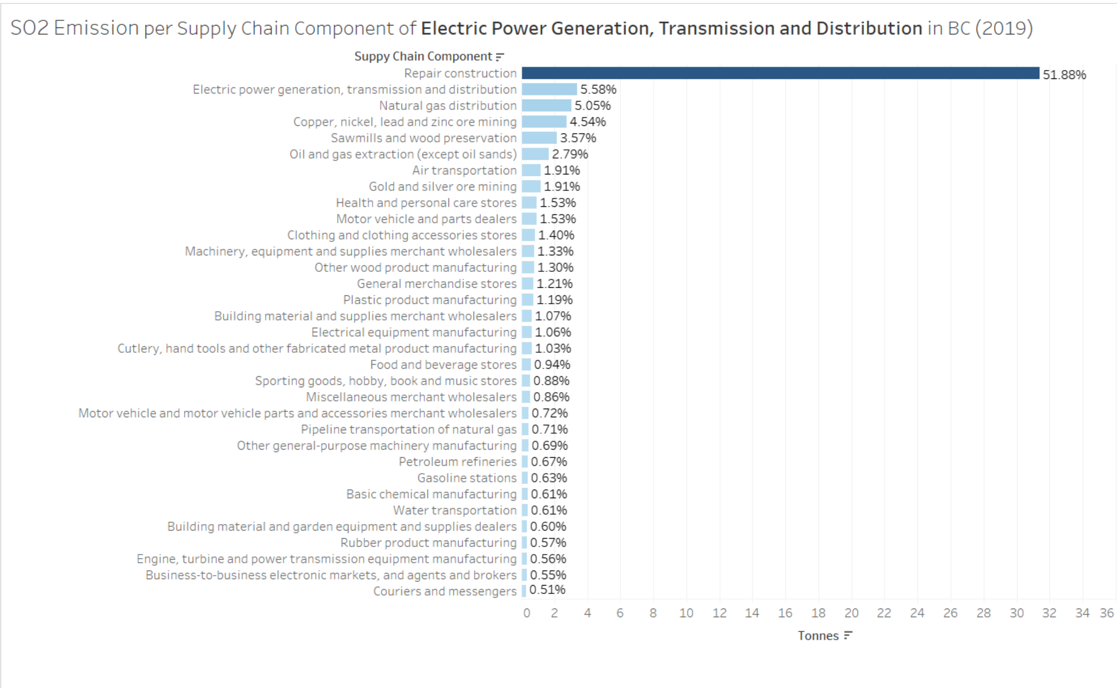
SO2 Released in Air by Fossil-Fuel Electric Power Generation & Other electric power generation Industry in British Columbia (2002-2021)



Note. SO2 Released in Air by Fossil-Fuel Electric Power Generation & Other electric power generation Industry in British Columbia (2002-2021). The data was adapted from Tableau Public Dashboard created for this analysis. https://public.tableau.com/views/SO2Emission-BC/Dashboard5?:language=en-US&publish=yes&:display_count=n&:origin=viz_share_link

Figure 18

SO2 emission per supply chain components of Electricity Power Generation, Transmission, and Distribution Industry in BC (2019)



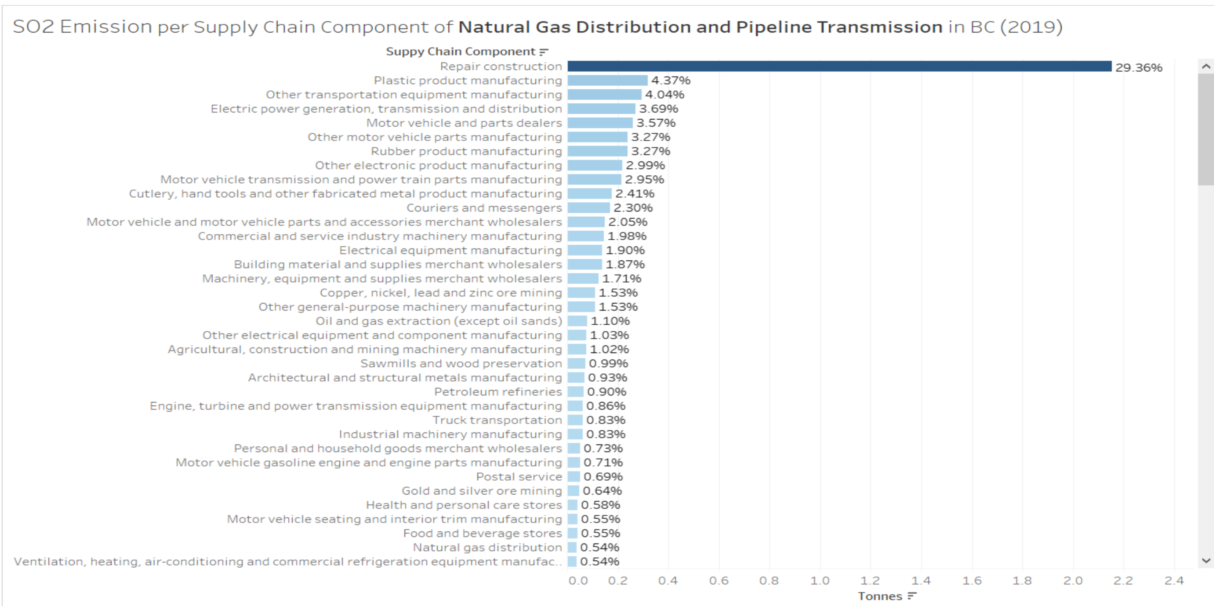
Note. SO2 emission per supply chain components of Electricity Power Generation, Transmission, and Distribution Industry in BC (2019). The data was adapted from Tableau Public Dashboard created for this analysis. https://public.tableau.com/views/SO2EmissionperSupplyChainComponentinBC2019/Dashboard4?:language=en-US&publish=yes&:display_count=n&:origin=viz_share_link

4.2.2 Natural Gas and Pipeline Transmission

The Natural Gas and Pipeline Transportation Industry's SO2 emission per supply chain component had a total emission of 7.34 tonnes in 2019. It is found that the top 5 contributing components include Repair Construction, Plastic Product Manufacturing, Other Transportation Equipment Manufacturing, Electric Power Generation, Transportation and Distribution, and Motor Vehicle and Parts Dealers.

Figure 19

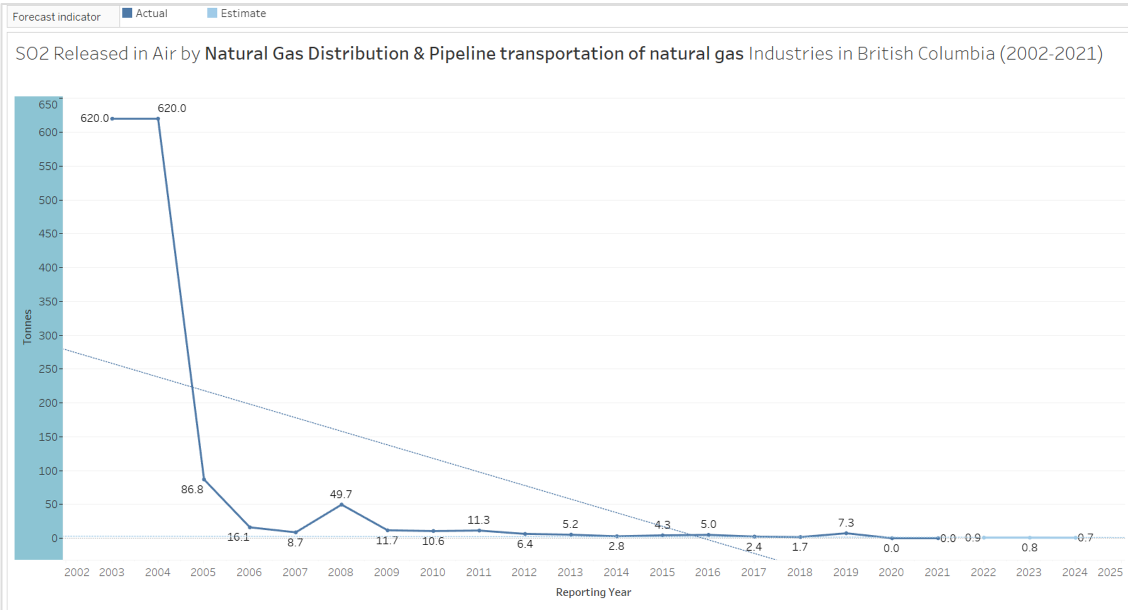
SO2 emission per supply chain components of the Natural Gas and Pipeline Transmission Industry in BC (2019)



Note. SO2 emission per supply chain components of the Natural Gas and Pipeline Transmission Industry in BC (2019). The data was adapted from Tableau Public Dashboard created for this analysis. https://public.tableau.com/views/SO2EmissionperSupplyChainComponentinBC2019/Dashboard4?:language=en-US&publish=yes&:display_count=n&:origin=viz_share_link

Figure 20

SO2 Released in Air by Natural Gas Distribution & Pipeline Transportation of Natural Gas Industries in British Columbia (2002-2021)



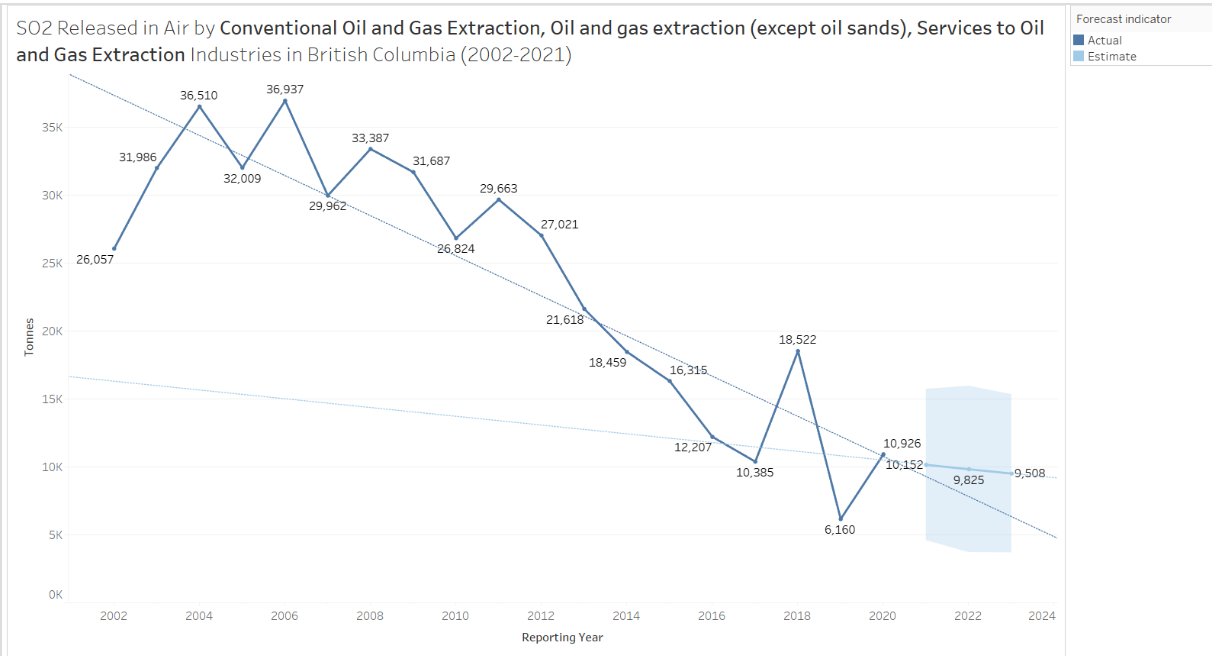
Note. SO2 Released in Air by Natural Gas Distribution & Pipeline Transportation of Natural Gas Industries in British Columbia (2002-2021). The data was adapted from Tableau Public Dashboard created for this analysis. https://public.tableau.com/views/SO2Emission-BC/Dashboard5?:language=en-US&publish=yes&:display_count=n&:origin=viz_share_link

4.2.3 Oil and Gas Extraction

The Oil and Gas Extraction Industry has a total SO2 emission of 6159.81 tonnes. This is the highest part of SO2 emission in the Utility Sector and Dependent Industries in BC for 2019. The analysis found that the top 5 contributors of SO2 emission for the supply chain of BC in 2019 were Supporting activities for Oil and Gas Extraction, Steel Product Manufacturing from the purchased steel, Repair Construction, Petroleum Refineries, and Machinery, equipment, and supplier merchant wholesalers.

Figure 21

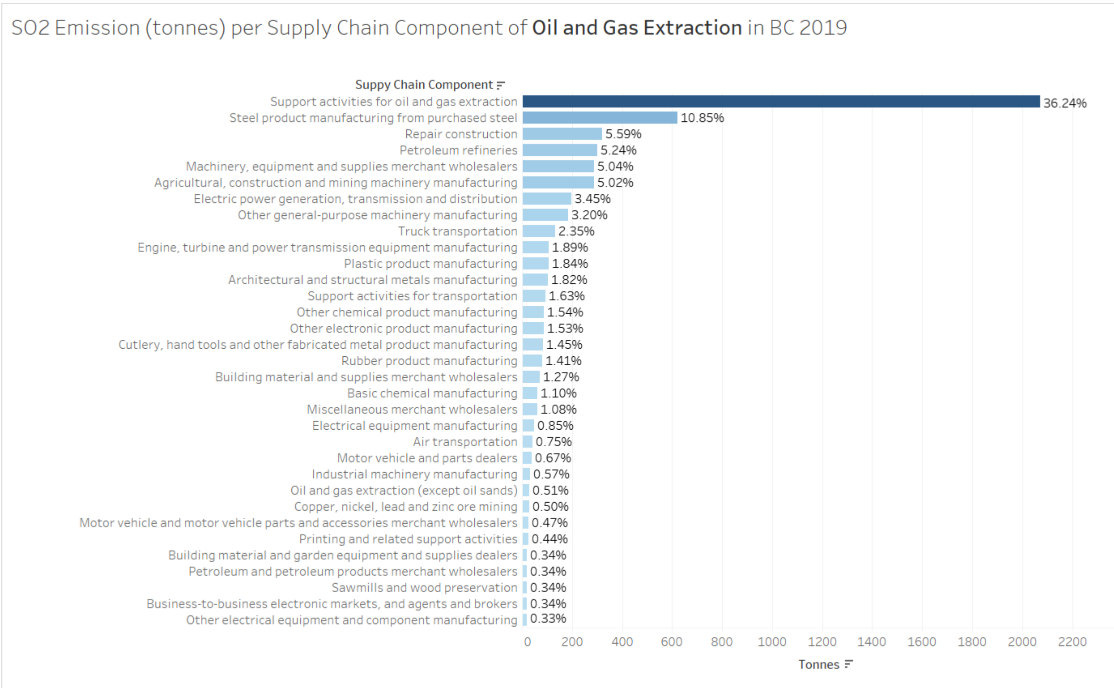
The SO2 Released in Air by Conventional Oil and Gas Extraction, Oil and Gas Extraction (except oil sands), and Services to Oil and Gas Extraction Industries in BC (2002-2021)



Note. The SO2 Released in Air by Conventional Oil and Gas Extraction, Oil and Gas Extraction (except oil sands), and Services to Oil and Gas Extraction Industries in BC (2002-2021). The data was adapted from Tableau Public Dashboard created for this analysis. https://public.tableau.com/views/SO2Emission-BC/Dashboard5?:language=en-US&publish=yes&:display_count=n&:origin=viz_share_link

Figure 22

SO2 emission per supply chain components of Oil and Gas Extraction in BC (2019)



Note. SO2 emission per supply chain components of Oil and Gas Extraction in BC (2019). The data was adapted from Tableau Public Dashboard created for this analysis. https://public.tableau.com/views/SO2EmissionperSupplyChainComponentinBC2019/Dashboard4?:language=en-US&publish=yes&:display_count=n&:origin=viz_share_link

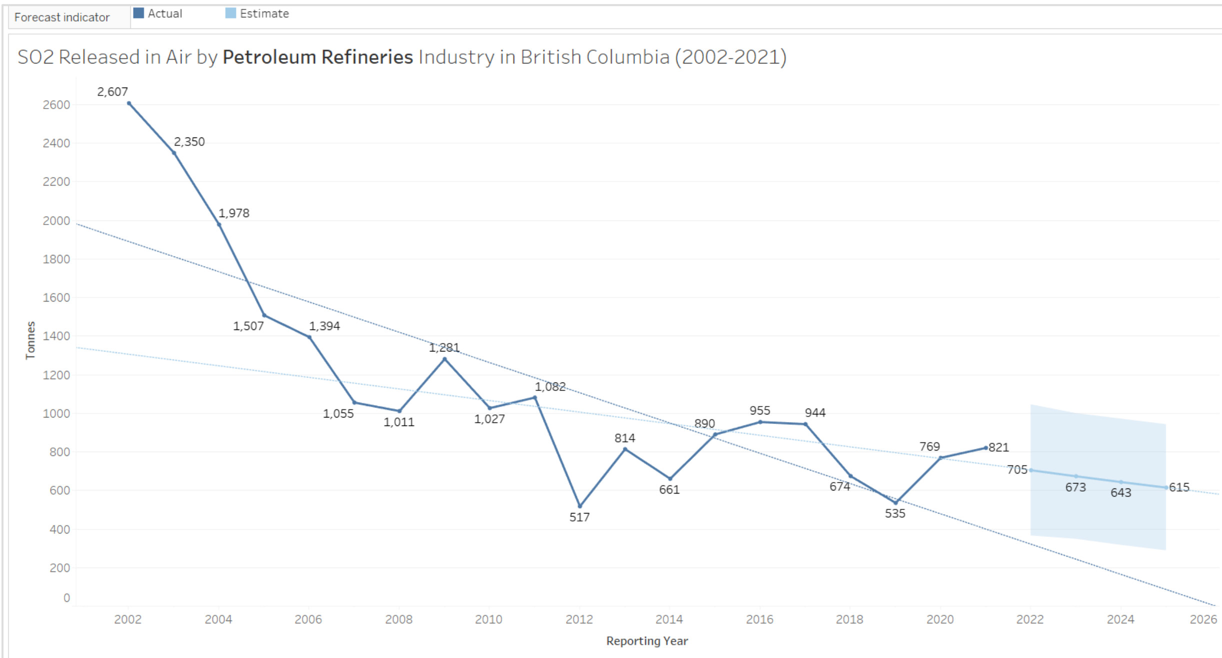
4.2.4 Petroleum Refineries

The Petroleum Refineries Industry in BC has the second-highest SO2 emission in the Utility Sector of BC in the year 2019. The industry's total SO2 emission was 535.30 tonnes in 2019. The top 5 supply chain components of SO2 emission for the Petroleum and Refineries industry include Oil and Gas Extraction (Except Oil Sands), Oil Sands Extractions, Crude Oil and

Other Pipeline Transportation, Petroleum Refineries, and Electric Power Generation, Transmission and Distribution.

Figure 23

SO2 Released in Air by Petroleum Refineries Industry in British Columbia (2002-2021)



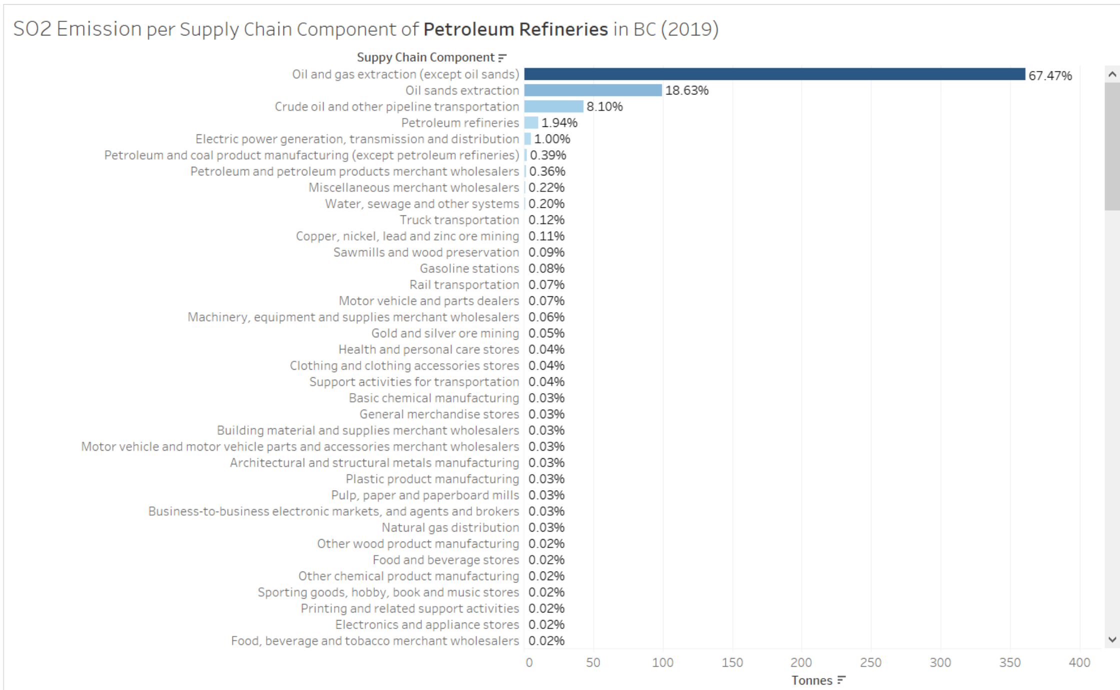
Note. SO2 Released in Air by Petroleum Refineries Industry in British Columbia (2002-2021).

The data was adapted from Tableau Public Dashboard created for this analysis.

https://public.tableau.com/views/SO2Emission-BC/Dashboard5?:language=en-US&publish=yes&:display_count=n&:origin=viz_share_link

Figure 24

SO2 emission per supply chain components of Petroleum Refineries in BC (2019)



Note. SO2 emission per supply chain components of Petroleum Refineries in BC (2019). The data was adapted from Tableau Public Dashboard created for this analysis. https://public.tableau.com/views/SO2EmissionperSupplyChainComponentinBC2019/Dashboard4?:language=en-US&publish=yes&:display_count=n&:origin=viz_share_link

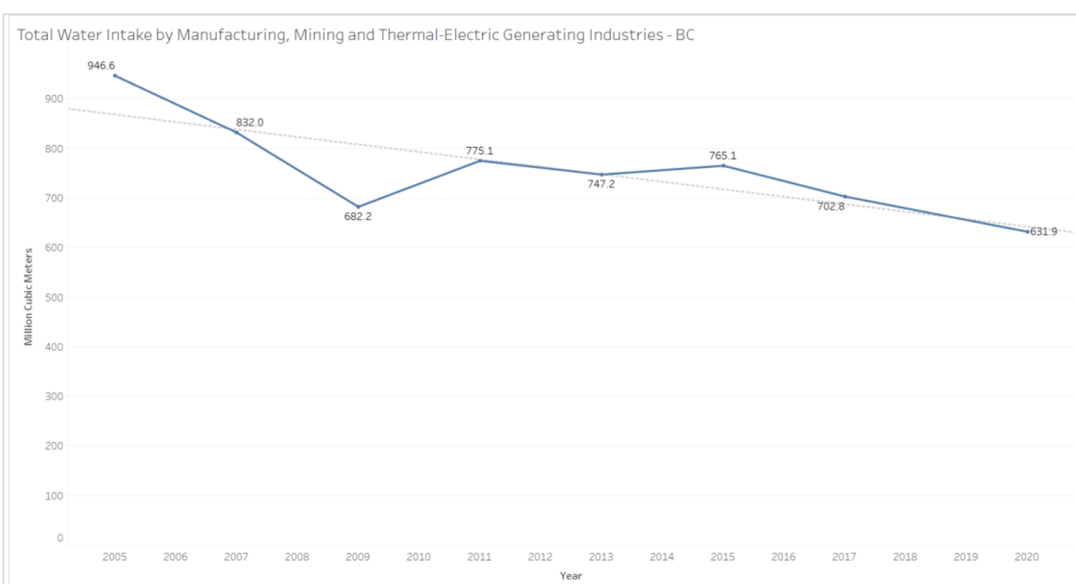
4.3 Water Footprints

Thermal-electric power producers have consistently remained Canada's largest industrial water consumers since 2005, as indicated by the data collected in the 2020 Industrial Water Survey. According to the survey, the three main sectors covered accounted for a total water intake of 27.2 billion cubic meters in 2020, showing a slight decrease of 1.4% from the previous data available in 2017. Among these sectors, power producers accounted for the majority at 84.4%, followed by manufacturers at 14.0% and the mining sector at 1.7%.

Within the manufacturing sector, five specific industries represented nearly 95% of the water intake in 2020. These industries include paper, primary metals, chemicals, food, petroleum, and coal product industries. Regarding the sources of water intake for industrial users, self-supplied surface water remained the primary source, constituting 88% of the total water intake. Furthermore, after usage, most of the water consumed for industrial processes was returned to the original water supply. Before being discharged, these industries implemented water recirculation practices. In 2020, approximately 18.2 billion cubic meters of water were recirculated, indicating a decrease of 15.5% compared to 2017. Thermal-electric power producers accounted for 85.2% of this total, manufacturing industries comprised 12.6%, and mining industries comprised the remaining 2.2%.

Figure 25

Total Water Intake by Manufacturing, Mining, and Thermal-Electricity Generating Industries in BC



Note. Total Water Intake by Manufacturing, Mining, and Thermal-Electricity Generating Industries in BC. The data was adapted from Tableau Public Dashboard created for this analysis. https://public.tableau.com/views/WaterFootprintsbyIndustriesinBCCanada/Sheet1?:language=en-US&:display_count=n&:origin=viz_share_link

5. Conclusions and Recommendations

This research study examined the environmental sustainability performance of the supply chain within British Columbia's (BC) utility sector, focusing on carbon, sulfur dioxide, and water footprints. Through the utilization of an input-output framework (Leontief, 1986) and analysis of reliable government data sources, valuable insights were gained regarding the sector's sustainability performance. However, several limitations were identified, including potential inaccuracies associated with data sources and the study's limited Scope within BC's utility sector.

5.1 Conclusion

In conclusion, this study sheds light on the environmental sustainability performance of British Columbia's utility sector, providing valuable insights for policymakers, industry stakeholders, and researchers. The findings emphasize the importance of transitioning to renewable energy sources to reduce greenhouse gas emissions and improve sustainability. The study also highlights the progress made in the natural gas sector in mitigating GHG emissions through measures targeting methane emissions. Water footprint calculations faced challenges due to data gaps and inconsistencies, suggesting the need for improved data collection processes and qualitative analysis to enhance the accuracy and comprehensiveness of sustainability assessments.

The study's utilization of the input-output framework effectively assesses inter-industry linkages within the supply chain while acknowledging the simplifying assumptions and limitations associated with this approach. These insights can inform future studies to refine the methodology and expand its application. Overall, this research provides a foundation for driving sustainable practices within BC's utility sector. By incorporating the study's findings into decision-making processes, policymakers and industry stakeholders can prioritize actions that lead to positive environmental outcomes. Collaboration, robust monitoring systems, and ongoing research efforts are essential in advancing the sector's sustainability goals. In addition to these conclusions, the following recommendations are proposed to further enhance the environmental sustainability of BC's utility sector and guide future research endeavors.

5.2 Recommendations

5.2.1 For Future Research

1. The scope of research can be extended to encompass other sectors and regions, considering their distinct supply chain characteristics and environmental impacts, as also suggested by Lenzen et al., 2012.
2. This research has tried to evaluate the performance of sustainability of the supply chain of BC's utility sector. Considering limited references and past research on this topic for BC, the topic can become challenging to yield quality results. Researchers can divide this topic and use this paper as a guide to explore the horizon further in this direction.
3. Improve data collection processes to address gaps and inconsistencies, especially regarding water footprints, and establish comprehensive and standardized data collection methods.
4. Assess the indirect effects within the supply chain environment, such as consumer behavior models, technological change scenarios, policy interventions, and market dynamics, to better understand the sector's sustainability performance (Hertwich et al., 2015).

5. Incorporate qualitative analysis to capture the socio-economic impacts associated with sustainability performance and provide a more holistic understanding of the sector's sustainability challenges and opportunities, as suggested by Estacio (2014).
6. Explore the use of scenario analysis and predictive modeling to project future environmental impacts based on policy scenarios, technological advancements, and changes in consumer behavior. This can be helpful, as suggested by the work of Wiedmann (2013) and others.

5.2.2 For Government

1. Foster collaboration and partnerships among government entities, industry stakeholders, and the public to promote knowledge sharing, innovation, and collective efforts in driving sustainable practices (Hahn et al., 2015). There is very limited data and research available for direct calculation of the sustainability performance of Industries in BC. Government should promote and incorporate strong measures to fill in the gap. This research paper can be used as an asset in that direction.
2. Implement robust monitoring and reporting systems to assess progress, identify areas for improvement, and ensure transparency in sustainability initiatives (Kolk & Pinkse, 2007).
3. Suppliers are an integral part of the supply chain process. This research found that there are no clear expectations for suppliers set by the industries or the BC Government. Thus, BC Government should encourage and promote supplier engagement by setting clear sustainability expectations and incorporating sustainability criteria in procurement processes for the industries in Utility Sector. This suggestion stands quite relevant to the other sectors as well.

5.2.3 Technical Recommendations

1. Enhance model validity by refining technical coefficients, incorporating more detailed inter-industry linkages, and accounting for multi-regional trade dynamics (Lenzen et al., 2012).
2. Address limitations of linear relationships and complex trade dynamics inherent in the input-output framework by exploring alternative methodologies that capture the nuances of the supply chain.

By considering these recommendations in future research endeavors, policymakers, industry stakeholders, and researchers can collectively strive to improve the environmental sustainability performance of BC's utility sector's supply chain. The findings have practical implications for enhancing supply chain sustainability, specifically in relation to carbon, sulfur dioxide, and water footprints, within BC's utility sector. Critical analysis and continued research efforts are crucial in driving sustainable practices and mitigating environmental impacts in the utility sector and beyond.

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